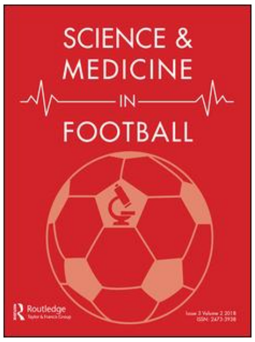

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Relationship between training load and recovery in collegiate American football players during pre-season training

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ABSTRACT

Background: The purpose of this study was to examine the relationship between training load and next-day recovery in collegiate American football (AF) players during pre-season.

Methods: Seventeen athletes (Linemen, n = 6; Non-linemen, n = 11) participated in the 14-day study wearing monitoring (accelerometer + heart rate) sensors during on-field practice sessions throughout pre-season to assess the physiological (PL), mechanical load (ML) and recording of session RPE (sRPE load) immediately post-practice. Prior to practice, participants completed a drop-jump reactive strength index (RSI) test and reported perceived recovery status (PRS). Loaded counter movement vertical jump was assessed before and after pre-season.

Results: For every one unit increase in sRPE load, RSI declined by 0.03. Non-linemen had a lower RSI value of 73.1 units compared to linemen. For every one unit increase in ML, the PRS decreased by 0.01. Non-linemen recorded higher average ML during week 2 (ES = 1.17) compared to linemen. Non-linemen recorded higher RSI values in weeks 1 (ES = −1.41) and 2 (ES = −1.72) compared to linemen. All training load and recovery parameters were lower week 2 compared to week 1 ($p < 0.05$) for all players.

Conclusions: Next-day RSI values were influenced by sRPE load while next-day PRS appears to be more influenced by ML. No difference in PL or sRPE load was observed been groups despite non-linemen completing a higher ML throughout the preseason. A combination of training load and recovery metrics may be needed to monitor the fatigue and state of readiness of each player.

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KEYWORDS
Practice load; recovery status; fatigue; preseason training

Introduction

Advancements in the development and application of wearable microtechnology, has led to novel insights into the physiological demands and quantification of external workloads in sport. These technologies may include a combination of global positioning systems, triaxial accelerometers, and heart rate monitors, which are often used to supplement visual feedback by providing objective markers of internal stress (e.g., heart rate) and external workload (e.g., distance covered, accelerations/decelerations, number of sprints, etc.). Both internal and external-based metrics are often interpreted as measures of training load, sometimes referred to as player load (as described previously (Boyd et al. 2011; Wellman et al. 2017), depending upon the software and user preference. A recent consensus statement established guidelines and best practices regarding monitoring athlete training loads, including how to best define training load, methods of measurement, and applications across different sports (Bourdon et al. 2017). The monitoring of training loads has been used in collision-based team sports, such as Australian Rules football (Gray and Jenkins 2010), American football (DeMartini et al. 2011; Wellman et al. 2016, 2017a) and rugby (McLellan and Lovell 2013; Cummins et al. 2018) to quantify competition demands, examine trends throughout different phases of the season, and to examine relationships between training load, recovery, and injury risk. Monitoring training loads throughout the season, may enable practitioners to identify the players at a higher risk of injury, which has been shown in Australian Rules football (Rogalski et al. 2013; Colby et al. 2014), American football (Wilkerson et al. 2016), and rugby (Gabbett and Domrow 2007). The threshold for what is classified as excessive is likely specific to the individual athlete as training history, nutritional intake, and sleep play an integral role in the athletes' ability to recover and tolerate the demands of training. Monitoring within a team-sport setting also allows for the development of unique position-group profiles to create opportunities for a more individualized approach to training load management.

American football (AF) is a collision-based team sport, consisting of high-intensity running mixed with jumping, backpedaling, accelerating, decelerating, and lateral movement (Wellman et al. 2016, 2017). At the American collegiate level, the typical play duration is ~5 sec. with an average work:rest ratio of 1:6 (Rhea et al. 2006; Iosia and Bishop 2008). In addition to high-intensity movement, AF players are engaged in collisions, blocking, and tackling activities that require a high degree of strength and power output. These physiological demands have been shown to elicit varying degrees in neuromuscular fatigue as seen in similar sports such as rugby and

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Australian rules football (Cormack et al. 2008a, 2008b; McLean et al. 2010; McLellan and Lovell 2012; Kennedy and Drake 2017). Performance-based metrics such as counter-movement vertical jump (CMVJ) or sprint tests have been used to provide objective, day to day measure of performance-based recovery and player readiness by serving as a surrogate measure of neuromuscular function and fatigue (Coutts et al. 2007b, 2007c; Montgomery et al. 2008). Such impairments in neuromuscular function have been reported in acute settings following post-match play in collision sports such as rugby (McLellan and Lovell 2012) and Australian football (Cormack et al. 2008a) as well as long term in-season phases in rugby (McLellan and Lovell 2013) and Australian football (Cormack et al. 2008b). Decrements in neuromuscular function may be magnified during periods of intensified training such as the pre-season period, as reported by Kennedy and Drake (2017) who identified notable increases in neuromuscular fatigue, (i.e., reductions in CMVJ performance), in the later period of pre-season training among academy rugby union players.

The AF pre-season training phase lasts two to four weeks and is designed to maximize training adaptations. Thus, practice frequency and intensity are often higher for the majority of pre-season practices compared to in-season (Wellman et al. 2017a). Preliminary evidence suggests the high congestion of training, common to the pre-season period, may negatively impact measures of subjective wellness (Wellman et al. 2017). In pre-season training, higher ratings of next-day fatigue were observed in AF players who recorded greater training loads, accelerations, decelerations, and distance covered in the preceding day's practice (Wellman et al. 2017). In a similar study, pre-training subjective wellness scores influenced a player's ability to perform an upcoming training session during a collegiate AF season (Wellman et al. 2017b). These relationships highlight the importance of assessing subjective measures of wellness to monitor recovery and player readiness. However, it is currently unknown how pre-season training impacts measures of day-to-day recovery status in AF players.

In AF, each position group has a unique role and tactical strategy, which subsequently leads to differences in movement profiles and training loads in practice and competition (Wellman et al. 2016, 2017, 2017a; DeMartini et al. 2011). Such discrepancies in movement demands across position groups may warrant the individualization of training loads to elicit necessary physiological adaptation. These differences in training load appear to remain consistent across different phases of the season (Wellman et al. 2017a). How positional differences in training load impact neuromuscular and subjective markers of recovery in AF players throughout the pre-season training period has not been established.

Currently, limited data exist in regard to the impact of internal and external measures of training load on next-day recovery as determined by drop-jump performance and subjective recovery scores during the pre-season training period in collegiate AF. Further, there remains a paucity of training load and recovery data for collegiate AF, despite more than 700 programs in existence across the United States. Therefore, the purpose of this study was to examine the relationship between training load and next-day measures of recovery in AF players during pre-season training. A secondary aim was to examine position group differences in training load and recovery during the pre-season. It was hypothesized that significant relationships would exist between training load and next-day recovery measures during pre-season training camp in collegiate AF players, and that significant differences in internal and external training loads would exist between position groups.

Materials and methods

Study design

This observational study was completed during a 14-day pre-season training period for National Collegiate Athletic Association (NCAA) Division III collegiate football players, which totaled 18 training sessions. Prior to the start of the preseason, subjects attended an informational meeting in which details of their participation were explained. During this study, subjects visited the Human Performance Laboratory twice for testing. Subjects first completed a baseline testing session that included body composition testing, and a loaded counter movement vertical jump (CMVJ) test, which was repeated after the completion of pre-season.

Throughout pre-season, subjects underwent daily monitoring before, during and after each practice. Prior to practice, subjects completed a perceived recovery status (PRS) questionnaire and reactive strength index (RSI) test to assess recovery status. During practice, subjects wore a microtechnology device to assess their physiological and mechanical load. After each practice, subjects completed a RPE (RPE) survey (within 30 min. of practice end) to provide an additional measure of training load. Subjects were asked to maintain regular dietary habits throughout the pre-season. Table 1 provides a summary of the testing protocol used throughout the study.

Subjects

Seventeen NCAA Division III AF players (Mean ± SD: Height: 1.80 ± 0.6 m; Body Mass: 99.1 ± 60.1 kg; Fat-free mass: 79.7 ± 8.6 kg; Body Fat%: 19.3 ± 8.6%) completed the study. Seven players were excluded from the analysis due to injuries and failure to participate in at least 80% of the practices. Subjects completed health history, exercise history, and signed

Table 1. Overview of research design.

	Prior to Pre-Season	Prior to Practice (Daily)	During Practice (Daily)	Post Practice (Daily)	Post Pre-season
Review & sign consent	✓				
Vertical Jump Test	✓				✓
Perceived Recovery Status		✓			
Reactive Strength Index		✓			
Physiological Load			✓		
Mechanical Load			✓		
Session RPE Load				✓	

consent forms prior to participation. Players were divided into two groups by linemen, which included offensive and defensive linemen, (L, n = 6) and non-linemen (NL, n = 11), (running backs, wide receivers, tight end, defense backs and linebackers). This study was conducted according to the Declaration of Helsinki guidelines and procedures were approved by the University's Institutional Review Board for use of human participants in research. Written consent was obtained from all subjects prior to data collection.

Baseline testing

Anthropometrics: Baseline testing occurred during the morning hours (05:00–09:00 after a 12 hr. fast. Height and body mass (BM) were assessed using a physician scale (*Health-o-meter, Hilton Medical Supply, WI, USA*). Body composition was assessed using air displacement plethysmography (*BODPOD, Cosmed, USA*) for determination of fat-mass (FM) and fat-free mass (FFM).

Loaded Counter-movement Vertical Jump Test: Athletes completed a standardized warmup followed by a loaded CMVJ. The warm-up consisted of a 200 m jog, followed by five body weight lunges per side, 10 body weight squats, and three tuck jumps. The same researcher supervised all CMVJs on a Smith machine (*Plyometric Power System; Norsearch, Australia*). Subjects were instructed to jump as explosively as possible while firmly securing the bar to their upper body. A 27″ x 27″ jump mat (*Just Jump System, Probotics, AL, USA*) was used to record jump height derived from flight time which was instantaneously calculated and presented on a digital display as described previously (McMahon et al. 2016). The jump mat has previously been shown to be strongly correlated to criterion measures of flight time (r = 0.969) and jump height (r = 0.972) using a force plate in elite rugby players (Dobbin et al. 2017). Body mass plus a standard load of 33 kg and the results of the CMVJ height were later used for the determination of vertical jump peak power (VJPP) according to previously published methods (Wright et al. 2012). Within three days after the completion of pre-season, subjects repeated CMVJ testing using the same protocol.

Recovery status determination

Approximately 30–45 min prior to practice each day, players completed the aforementioned supervised warm up and a 5-minute recovery. Next, players completed a drop-jump reactive strength index (RSI) test as used by Young (1995). For the drop-jump RSI test, players performed a drop jump by stepping off a 30 cm box, with hands on their hips, landing on a contact mat from which they were instructed to jump as high as possible immediately upon landing. Players completed three separate jumps with the best score recorded. Jump height and contact time were recorded using a jump mat (*Just Jump System, Probotics, AL, USA*). The RSI was determined as a ratio between the jump height (cm) and the contact time (sec) during the drop jump (RSI = jump height/contact time) which were instantly displayed on a digital dashboard following each jump. Following the RSI test, players also completed a PRS questionnaire, which is a validated tool to assess subjective ratings using a ranking system (0–10) in addition to short phrases anchored to each value (Table 2) (Laurent et al. 2011). The PRS scale has previously been shown to be associated with changes in performance when used following warm up (r = −0.63) and be able to predict performance outcomes within a reasonable degree of accuracy (Laurent et al. 2011). The players were instructed to rate how they physically felt in terms of recovery from the previous practice and their perceived readiness for the upcoming session.

Table 2. Session ratings of perceived exertion and perceived recovery status scales.

sRPE Description	Rating	PRS Description
Maximal	**10**	*Very well recovered/highly energetic*
	9	
	8	*Well recovered/somewhat energetic*
Very Hard	**7**	
	6	*Moderately recovered*
Hard	**5**	*Adequately recovered*
Somewhat Hard	**4**	*Somewhat recovered*
Moderate	**3**	
Easy	**2**	*Not well recovered/somewhat tired*
Very, Very Easy	**1**	
Rest	**0**	*Very poorly recovered/extremely tired*

Modification of the Category Ratio Rating of Perceived Exertion Scale. Adapted from Foster et al. 2001.
sRPE = session ratings of perceived exertion; PRS = perceived recovery status.

Practice load determination

Players were equipped with a *Bioharness* monitoring strap that included an accelerometer and heart rate sensor (*Bioharness^{TM} 3, Zephyr Technology Corp., Annapolis, MD, USA*) to determine the mechanical and physiological load of each practice. Research in controlled laboratory and field-based settings has established the Bioharness^{TM} as a valid and reliable measure of accelerometer-derived metrics and heart rate (Johnstone et al. 2012, 2012a, 2012b). The mechanical load is a metric used to quantify the volume and intensity of practice activities using the accumulation of mechanical intensity as determined by the proprietary software program (*PSM Training, Zephyr Technology Corps., Annapolis, MD, USA*). Mechanical load was determined by summating the systems mechanical intensity values, which was determined by the highest peak acceleration in the vertical, lateral, or sagittal axis of the internal triaxial accelerometer during each second epoch sampled at 100 Hz. The mechanical intensity is determined by the acceleration (g) forces on a 0–10 linear scale, in which 0.5 g equals 0 and > 6 g equals 10. Physiological load was determined similar to mechanical load; however, using physiological intensity, a heart rate-based metric rather than movement based. Physiological intensity is determined on a 0–10 linear scale in which 50% of age-predicted heart rate equals 0 and 100% age-predicted max equals 10. The device was fixed to a chest strap and worn under the player's shoulder pads. Immediately following practice, players completed a modified sRPE questionnaire (Foster 1998), which was multiplied by the training session duration to determine session RPE load (sRPE load) and provide another measure of training load. The players were instructed to rate the global intensity of the entire session while being provided the verbal anchors of each numerical value on the scale using a modified version of Borg's category ration 10-point scale as depicted in Table 2. The sRPE questionnaire has been previously shown to be a valid measure of internal training load in football players with correlation coefficient values ranging from r = 0.7–0.85 for several measurements of external training load (Scott et al. 2013).

Statistical analysis

Participant demographic data are presented using descriptive statistics. Daily training load values (i.e., Physiological load, Mechanical load, and sRPE load) were matched with the next day recovery outcome of reactive strength index and perceived recovery status (i.e., physiological load Day 2 had the outcome value from reactive strength index day 3). A multilevel model with repeated measures was fit. The mixed model was fit by using Akaike's Information Criteria (AIC) and Bayesian Information Criteria (BIC) along with the importance of the variables to determine which covariates to keep in the model. The subject intercept was a random effect, while practice day, physiological load, mechanical load, position, and sRPE load were fixed effects. Daily training loads (mechanical load, physiological load, and sRPE load) and recovery values (perceived recovery status and reactive strength index) were collapsed and an analysis of variance was used to determine differences in training load and recovery scores between position groups for each week. A repeated measures ANOVA was used to examine differences in daily mechanical load and reactive strength index with position group serving as the between-subjects factor and practice day as the within-subjects factor. Follow-up pairwise differences were used to determine the magnitude of difference between position groups. Changes in lower body power were analyzed using paired-samples t-tests. Data are reported as mean ± SD with 95% confidence intervals and considered statistically significant when the probability of type I error was 0.05 or less. Cohen's *d* effect sizes (ES) were calculated and interpreted using the following criteria: ≤0.2 = trivial, 0.2–0.6 = small, 0.7–1.2 = moderate, 1.3–2.0 = large, and ≥2.0 = very large All analyses were completed using Microsoft Excel and the Statistical Package for the Social Sciences (*v26; SPSS Inc., Chicago, IL, USA*).

Results

The intra-class correlation coefficient (ICC) was calculated and was r = 0.778 for player regarding RSI values. There was a significant effect (p = 0.002) for sRPE load in the model with RSI as the outcome. For every one unit increase in sRPE load, RSI declined by 0.03. A significant effect for position group (p = 0.002) was observed with RSI as the outcome. NL had a lower RSI value of 73.1 units compared to L. Neither ML nor PL had a significant effect on RSI. The results of the full regression model for RSI are presented in Table 3.

Table 3. Full model with RSI as the outcome.

	Estimate (SE)	p-value
Intercept	306.0 (16.3)	
Day	−3.1 (0.4)	<0.001
Mechanical Load	−0.06 (0.09)	0.55
Physiological Load	−0.02 (0.02)	0.22
Session RPE Load	−0.03 (0.01)	0.002

ICC was calculated and was r = 0.239, for player regarding PRS. Mechanical load was significant (p = 0.015) in the model with PRS as the outcome. For every one unit increase in ML, the PRS decreased by 0.01. Neither PL nor sRPE load had a significant effect on PRS. Individual player was a random effect in the model to account for the assumption that each player over time would have similar time results, regardless of the time point. The results of the full regression model for PRS as the outcome are presented in Table 4.

Table 4. Model with PRS as the outcome and all variables of interest.

	Estimate (SE)	p-value
Intercept	7.32	
Practice Day	−0.07 (0.02)	0.001
Mechanical Load	−0.01 (0.004)	0.015
Physiological Load	0.0001 (0.001)	0.882
Line vs Non-line Position	0.21 (0.41)	0.606
Session RPE Load	−0.001 (0.0004)	0.050

The NL group recorded higher average mechanical loads during week 2 ($p < 0.047$; ES = −1.17) compared to L. No differences in sRPE load or physiological load were observed between position groups for either week ($p > 0.05$) when examined as a weekly average as seen in Figure 1.

All training load and recovery parameters were significantly lower week 2 compared to week 1 ($p < 0.05$) for both NL and L. The NL group produced higher RSI values in weeks 1 (p = 0.023; ES = −1.41) and 2 ($p < 0.01$; ES = −1.72) compared to L. Table 5 provides a summary of differences in training load and recovery parameters across each week by position group.

Repeated measures ANOVA indicated significant differences between position groups for daily mechanical load and reactive strength index as presented in Figure 2.

Reductions in VJPP were observed following the pre-season period compared to baseline testing (−220.24, [−9.05, 449.53] watts; ES = 1.26 for both position groups combined. The NL group experienced a larger reduction in VJPP compared to L (80.92, [−415.33, 577.16] watts; ES = −0.19).

Discussion

The primary aim of the current study was to examine the relationship between training load and next-day recovery parameters in AF players during fourteen days of pre-season training. The findings from the current study indicate that as the perceived practice difficulty (sRPE load) increased throughout pre-season, the next-day RSI scores declined, which is likely an indication of neuromuscular fatigue and supports our initial hypothesis. Specifically, for every one unit increase in sRPE load there was a – 0.03 decrease in RSI and for a given sRPE load, L were predicted to have an RSI score that is 73.1 units lower. To clarify further, when comparing a L and NL on the same day if the L had a sRPE value that was 5 points greater than the NL, the L would have an estimated score that was 73.25(−73.1 + (−0.03*5)) points lower than a NL. However, neither ML nor PL had a significant effect on RSI. These findings suggest that an athlete's perception of practice difficulty has a greater influence on indices of next-day neuromuscular recovery than objective measures of internal (PL) and external (ML)

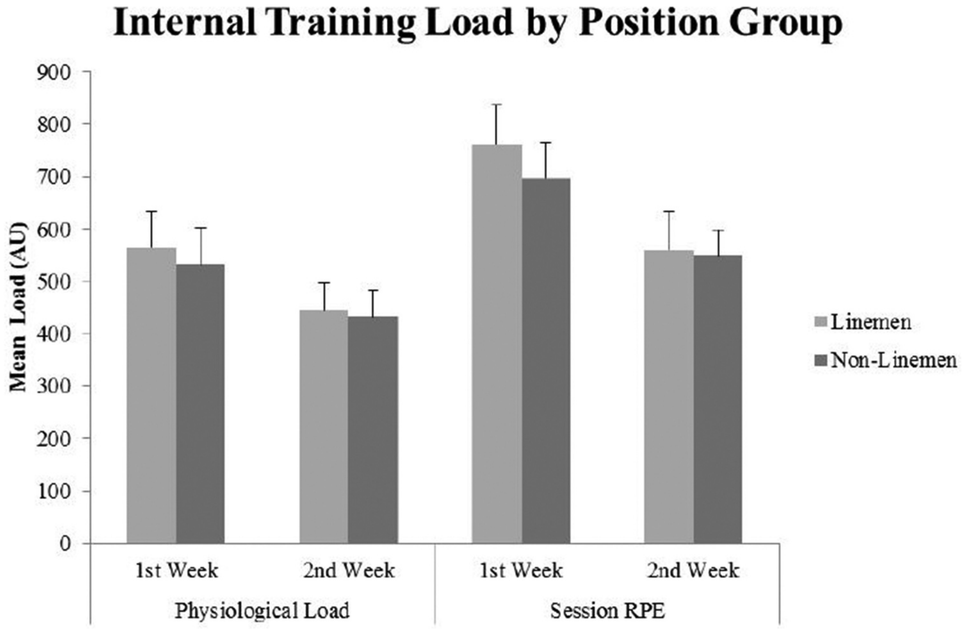

Figure 1. Internal training load (mean ± SD) during preseason training by position group.

Table 5. Differences in recovery and training load parameters across each week of pre-season by position group. Data presented as Mean ± SD. Delta values presented as mean (95% Confidence intervals).

	L					NL				
Training Load	Week 1	Week 2	Delta	p value	ES	Week 1	Week 2	Delta	p value	ES
ML (AU)	105.2 ± 27.3	93.4 ± 11.4	11.81 (−2.55, 26.18)	.223	.56	126.6 ± 24.7	110.5 ± 17.3	16.05 (6.73, 25.36)	.003	.76
PL (AU)	564.3 ± 137.3	445.0 ± 103.5	119.31 (−17.20, 255.83)	.075	.98	532.3 ± 140.4	432.9 ± 97.5	39.29 (159.33)	.004	.82
sRPE Load (AU)	761.5 ± 149.7	560.6 ± 146.2	200.94 (119.37, 282.51)	<.001	1.36	697.2 ± 133.7	548.9 ± 97.7	148.37 (83.94, 212.81)	<.001	1.27
Recovery										
RSI (cm/sec)	218.9 ± 33.08	196.0 ± 23.1	22.91 (10.80, 35.02)	.005	.80	290.1 ± 63.5	271.4 ± 57.6	18.71 (3.62, 33.79)	.020	.31
PRS (AU)	6.45 ± 1.4	5.56 ± 0.59	.865 (−.46, 2.19)	.153	.83	5.85 ± 1.3	5.46 ± 0.85	.39 (−.40, 1.18)	.294	.36

ML = Mechanical load; PL = Physiological load; sRPE = session rating of perceived exertion load; RSI = Reactive strength index; PRS = Perceived recovery status; NL = Non-linemen, L = Linemen; ES = Effect size.

training load which is in alignment with previous findings supporting the use of subjective self-reported measures of training load as a tool for monitoring the athlete training response (Saw et al. 2016). It is possible that sRPE load is able to better account for physiological stressors imposed on the athlete that are not able to be detected via external load metrics or movement kinematics. For example, high-impact collisions, isometric, and dynamic activities such as blocking, rushing, or holding that require a high-degree of effort yet may not be detectable by GPS or accelerometry could result in a high degree of imposed stress and subsequent fatigue, which may contribute to the athlete's perception of training session difficulty. Mechanical load was the only metric that had a significant impact on next-day PRS scores with a trend for sRPE load to impact next-day PRS values thereby indicating that ML and sRPE load both may determine an athlete's perception of recovery. These results are also in alignment with previous findings that indicate training load has an impact on subjective measures of recovery in athletes during periods of high training volumes (Buchheit et al. 2013; Wellman et al. 2017). For example, Buchheit et al. (2013) observed reductions in wellness scores in accordance with an increase in daily training load in elite Australian Rules football players during a two-week pre-season training period, and determined that wellness measures could serve as an effective measure for monitoring training responses. Interestingly, Buchheit et al. (2013) noted, that despite the relatively high training loads observed during the pre-season period compared to other team sports (10,000 AU vs. 2,000–4,000 AU), the players tolerated the training loads well from a physical standpoint as sport-specific sprint performance was not negatively impacted following the pre-season period. Wellman et al. (2017) similarly noted a strong relationship between player load (a proprietary metric used to quantify the sum of accelerations across all axes of movement) and distance covered from practice on next-day ratings of perceived wellness in AF players. It is worth noting that relationships between training load and perceptions of recovery may also be susceptible to the influence of outside factors such as

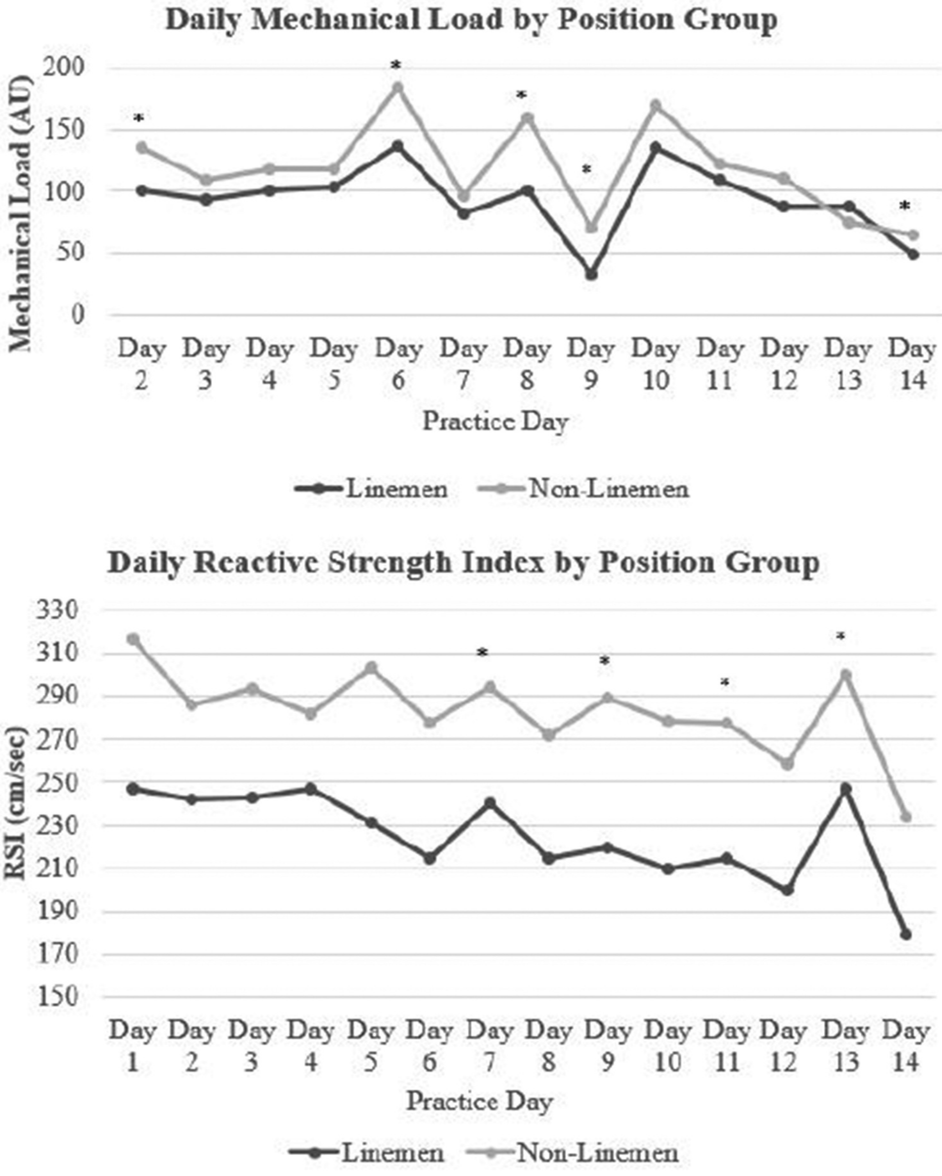

Figure 2. Daily changes in mechanical load and reactive strength index by position group during preseason training. *Signifies significant difference between groups.

environmental conditions, nutritional intake, sleep, and life stressors that could impact perceptions of recovery or player readiness.

In the current study, all indices of training load (i.e., physiological load, mechanical load, and sRPE load) were lower in week 2 relative to week 1. However, despite reductions in training load, RSI and PRS values were lower in week 2 relative to week 1 suggesting the players experienced an increased state of fatigue (neuromuscular and subjective) throughout the pre-season training period. Additionally, loaded CMVJ performance was also lower following the pre-season period compared to baseline. These findings are in alignment with previous research that has indicated periods of intensified team-sport training and competition results in an accumulated fatigue-effect as indicated by reduced performance or indicators of recovery (Coutts et al. 2007a; Cormack et al. 2008b; Buchheit et al. 2013; Johnston et al. 2013). Specifically, increased neuromuscular fatigue has previously been reported following single rugby and Australian Rules football competitions (Cormack et al. 2008a; McLellan and Lovell 2012) and after a multi-day rugby competition (Johnston et al. 2013). Johnston et al. (2013) reported notable reductions (ES = −0.73) in lower body power determined by CMVJ performance after only a 5-day tournament in rugby players. Neuromuscular fatigue identified through CMVJ testing has also been observed following longer periods of intensified pre-season and off-season training in Rugby players (Coutts et al. 2007a; Argus et al. 2010). However, repeat measurements of neuromuscular function throughout longer period of training or season duration may provide additional benefits by allowing practitioners to distinguish between acute perturbations in neuromuscular performance following acute bouts of intensified training and competition or a continued state of neuromuscular fatigue. Yet, limited evidence is available regarding whether or not a continued state of neuromuscular fatigue would persist throughout an entire season and its potential impact on performance. Cormack et al. (2008b) employed a continual CMVJ testing protocol throughout a 22-match season and noted 60% of in-season assessments were substantially below pre-season values, which were also accompanied by elevated cortisol levels. Cormack et al. (2008b) concluded these disruptions in CMVJ performance and cortisol levels indicated a sustained state of incomplete recovery throughout the season. More work is needed to determine how such a sustained state of fatigue may impact sports performance capabilities throughout the season and into post-season competition. Generally, a brief reduction in training volume and/or intensity using a tapering strategy following a period of intensive training such as pre-season training, is sufficient to restore strength and power (Bosquet et al. 2007; Coutts et al. 2007a, 2007b). However, this presents challenges to coaches when a pre-season period is immediately followed by the competitive season, especially when early season games have implications for post-season.

A secondary aim of the current study was to examine differences in training load and recovery between position groups during pre-season training in collegiate AF players. Results indicated that NL experienced a higher mechanical load during week 2 of preseason compared to L when expressed as a weekly average. Non-linemen also tended to experience a higher mechanical load throughout all of pre-season as seen in Figure 2. Interestingly, despite higher mechanical loads, higher physiological loads among NL were not observed. These results provide novel findings in that despite differences in mechanical loads between position groups, this did not translate to differences in physiological loads. This discrepancy indicates while the mechanical measures of workloads may be different, the underlying physiological demands or 'costs of practice' appear to be comparable between position groups. No differences in subjective measures of internal load or sRPE load were observed between position groups as well. Previous findings by DeMartini et al. (2011) reported greater workloads for AF non-linemen during pre-season with a higher heart rate max also observed for non-linemen compared to linemen which is somewhat contradictory to findings from the current study. However, the differences in measurement techniques to quantify the physiological response to training were different between those used by DeMartini et al. (2011) and in the current study as the physiological load metric calculated in the current study may not be sensitive enough to detect peak heart rate responses and rather are more appropriate to assess overall training intensity throughout an entire session. It is also worth noting that DeMartini et al. (2011) examined the physical demands of AF players competing in the southeastern region of the United States, which is significantly warmer and with higher indices of humidity compared to the current study's location (i.e., upper Mid-West), which may have resulted in a more exaggerated peak heart rate response. Regardless, the lack of differences in PL between position groups observed in the current study, indicates that, at the collegiate level, NL may be able to tolerate higher mechanical loads without a corresponding increase in physiological responses or perceptions of effort. It is also possible that although NL may undergo higher mechanical loads, likely resulting from an accumulation of high load running, they are not as involved with continual contact and collisions compared to L whose primary roles include blocking, rushing the passer and tacking at the line of scrimmage. Resultantly, physiological loads are likely similar, as seen in Table 5., as each position group is exerting comparable degrees of effort, albeit through different movement patterns, power outputs and degrees of contact or engagement in blocking and tackling activities which may otherwise be difficult to quantify. Although not an exact representation of the physiological demands of various position-specific activities, Wellman et al. (2017) previously reported that defensive tackles sustained more heavy and very heavy impact forces (1–10 G force) during game activities in NCAA Division I AF players compared to any other defensive positions. High impact collisions are just one of many position-specific activities that may subsequently influence physiological demands but are not able to be quantified by strictly relying on movement-based kinematic analysis. In the current study, RSI and PRS values were lower in week 2 relative to week 1 for both position groups indicating an accumulation of fatigue for all players. Interestingly, weekly average and daily RSI values were higher in NL despite undergoing higher ML throughout the pre-season period. Further, L experienced a more practically meaningful decrease (ES: 0.80) in RSI values from week 2 to week 1, compared to NL (ES: 0.31) thereby suggesting that NL may also be able to tolerate higher ML and PL without a greater magnitude of decline in neuromuscular function.

Differences in the movement profiles of L and NL during the pre-season period have been previously noted in AF (DeMartini et al. 2011; Wellman et al. 2017). DeMartini et al. (DeMartini et al. 2011) observed significantly more distance covered by NL with a higher distance also covered in higher speed zones. Similarly, Wellman et al. (2017) presented a detailed view of the GPS-derived movement characteristics during a pre-season period in NCAA Division I AF players and reported that defensive backs covered approximately 60% more distance compared to defensive linemen. Offensively, wide receivers covered approximately 65% more distance with roughly a 30% greater player load (a proprietary metric) compared to offensive linemen. In the same study, Wellman et al. (2017) also reported greater acceleration/deceleration distances at higher intensities for wide receivers and defense backs compared to linemen. Although not directly assessed in the current study, such differences in movement profiles between position groups likely explain the higher mechanical loads observed in the NL group. Greater mechanical loads, distances covered and distances covered in higher speed zones are somewhat expected as these positions require different tactical strategies during games thereby requiring differences in practice activities with position-specific movements, drills, and distances covered that are quite different from linemen. These positional differences in movement kinematics and external workload appear to remain during competitive games (Wellman et al. 2016), which supports the implementation of position-specific training during pre-season and in-season practice sessions.

A limitation of the current study is the small sample size, particularly when divided into position groups. Due to equipment limitations, only twenty-four players were enrolled in the monitoring project with 7 later being excluded from the final analysis due to injuries suffered throughout the pre-season period. Further, the current study period was 14-days. The observed relationships between training load and recovery may change throughout the course of an entire season. More research is warranted to determine the validity of different training load metrics before recommendations can be provided in regard to their applicability for teams throughout during phases of a season.

Practical implications

Results of the current study indicate that perceptions of training intensity can help predict next-day indices of neuromuscular fatigue. This application of sRPE load monitoring can provide value to smaller budget athletic programs who may not have resources to purchase advanced wearable technology systems. Furthermore, perceptions of recovery status appear to be more influenced by the preceding day's mechanical load thereby suggesting that both internal and external derivations of training load influence both neuromuscular and subjective indices of recovery and which should be considered when monitoring athletes. Additionally, positional differences in mechanical load are likely to occur throughout a pre-season training period and therefore certain positions may need to be monitored more closely for training stress-related declines in performance and recovery. A combination of metrics may provide the most robust profile of training loads and overall recovery scores.

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Data availability

The data can be made available upon request.

Disclosure statement

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