**A****rticle Type:** Original investigation

**THE RELATIONSHIP BETWEEN OBJECTIVE MEASURES OF SLEEP AND TRAINING LOAD ACROSS DIFFERENT PHASES OF THE SEASON IN AMERICAN COLLEGIATE FOOTBALL PLAYERS**

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**Running title:**

Sleep and training load in American Football \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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**Abstract**

Despite the perceived importance of sleep for American collegiate football (ACF) players, particularly given the schooling and athletic expectations for these players, descriptions of the duration and quality of sleep are limited. Thus, this study investigated the relationship between objective measures of sleep and training load across different phases of the season (Off-season, Camp [Pre-season], In-Season and School) in twenty-three ACF players (21.1±1.2 years; 108.0±20.0 kg). Participants’ sleep/wake behavior and daily external training load were assessed using wristwatch actigraphy and accelerometry (PlayerLoadTM [PL]), respectively for a minimum of 3 nights/days in each phase. The relationships between each sleep metric and both season phase and external training load were assessed using linear mixed models. Overall, total sleep time was *very* *likely* shorter in Camp (-41±13 min, effect size [ES 0.68±0.36[), *almost certainly* shorterIn-Season (-56±14 min, ES 0.93±0.39) and *likely* shorter in School (-28±15 min, ES 0.46±0.42) compared to the Off-season phase. There was *almost certainly* a difference in sleep latency during the school phase (ES=4.67±2.03). These data suggest sleep time is reduced during periods of intensified training in ACF players. Of further concern are the demands placed upon student-athletes during the School phase, where aspects of sleep can be compromised.

**Keywords:** Gridiron, accelerometer, night, recovery, performance, athlete

**Introduction**

Reductions in sleep quantity and/or quality have been found prior to, and following, competition in elite athletes (Erlacher et al. 2011; Juliff, Halson, and Peiffer 2015; Eagles and Lovell 2016). Such reductions are reported to reduce aspects of athletic performance (Reyner and Horne 2013; Jarraya et al. 2013; Edwards and Waterhouse 2009) and recovery (Skein et al. 2013), respectively. However, there is limited evidence to highlight that team-sport athletes, particularly American collegiate footballers (ACF), experience sleep issues whether in their normative behavioral state or at different stages of the season (Erlacher et al. 2011; Juliff, Halson, and Peiffer 2015; Fullagar, McCunn, and Murray 2017). This is concerning, given sleep is considered by athletes, practitioners and researchers alike to be integral in preparation and recovering from team-sport competition (Skein et al. 2013; Fullagar, Duffield, et al. 2015; Caia et al. 2017; Halson 2014). Furthermore, the combination of schooling and athletic expectations for ACF student-athletes (increasing the demand on their schedule), along with their at sleep-risk age cohort (60% of college students suffer from poor sleep quality (Lund et al. 2010)), would suggest ACF players may be highly susceptible to sleep disruption (Govus et al. 2018). It has been suggested that within collegiate student athletes, the commencement of class schedules can threaten sleep quality (Hershner and Chervin 2014) as training has to start earlier in the day (Fullagar et al. 2017). Therefore, further research investigating the behavioral sleeping patterns of American collegiate footballers is warranted.

At the Division 1A level (the highest level within NCAA Football) in the United States, there are typically four distinct stages of the season; Off-Season (typically Jan-March, June-July), Camp/Pre-Season (August), In-Season (Sept-Dec) and School periods (Oct - January). During the Off-season and in Camp, players are exposed to increased weight room/gym time and higher training volumes, respectively, in order to develop the necessary physical qualities to prepare for In-Season performance. Although a necessary part of training regimen, this may be an issue as intense and prolonged training periods are associated with sleep disturbances (Juliff, Halson, and Peiffer 2015; Hausswirth et al. 2014; Killer et al. 2015). During the ACF In-Season period training exposure will typically decrease, but players are exposed to games, which may expose additional sleep stressors such as playing at night, travel and psychological stressors associated with game play (Fullagar, Duffield, et al. 2015; Juliff, Peiffer, and Halson 2017). Finally, School periods are typified by increases in study and/or examination requirements (whilst still training and playing football towards the latter periods of In-Season) that may extenuate additional mental fatigue, anxiety and impede sleep quality (Fullagar et al. 2017). Taken collectively, there appear numerous factors within these four distinct phases of the ACF season where players may be exposed to sleep comprising situations; however peer-reviewed evidence pertaining to the analysis of the relationship between objective measures of sleep and associated factors within this cohort is unknown.

Recently, authors have investigated the relationship between sleep parameters and training characteristics in athletes. Thornton and colleagues (Thornton et al. 2018) observed reduced sleep durations, earlier bed times and a lower sleep efficiency alongside increases in total distance and high-speed distance loads; however increased acceleration/deceleration demands were associated with small increases in sleep duration and sleep efficiency during pre-season training in professional rugby league players. During an Australian Rules training camp, Pitchford and colleagues (Pitchford et al. 2016) reported that sleep duration was inversely associated with session rating of perceived exertion load (s-RPE). Although ACF has similar physiological concepts to rugby and Australian football, the varied positional demands (up to ten positions), game style (sustained periods of rest combined with short explosive play movements) and differing schedule of an NCAA student-athlete compared to professionals (i.e. attendance of classes, school stressors) suggests ACF players may be exposed to a unique variety of training and lifestyle stressors which could impact sleep, or vice versa (Fullagar, McCunn, and Murray 2017). Indeed, since sleep issues experienced by team-sport athletes are postulated to be predominately situational and sport-dependent (Juliff, Halson, and Peiffer 2015), it would appear a similar analysis of the relationship between sleep and training load conducted in other sports is required in ACF. Indeed, such studies that assist in furthering our understanding of how training and schooling demands of ACF athletes may disturb sleep, could aid in designing training programs which attenuate the probability for reduced sleep quantity/quality occurring.

Accordingly, the purpose of the present study was to examine the relationship between objective measures of sleep and external training load in ACF players across different phases of the NCAA D1 season.

**Methods**

***Subjects***

Twenty-three student athletes volunteered to participate (21.1±1.2 years; 108.0±20.0 kg; 189.0±6.8 cm). Players were football student-athletes at the Division 1 level in the NCAA. The group consisted of 10 defensive and 13 offensive players (Defensive Back = 5, Defensive Line = 3, Linebacker = 2, Offensive Line = 5, Quarterback = 2, Running Back = 1, Tight End = 3, Wide Receiver = 2). Prior to the commencement of the investigation written and verbal information about the research and its procedures was provided to all participants, before written informed consent was obtained. The research received ethical approval from the local institutional review board, and was conducted in accordance with the Declaration of Helsinki.

***Study Design***

The present longitudinal study was a descriptive, observational design. All players were familiarised with the study procedures prior to the collection of data. The study was conducted in the 2017 calendar year across the Off-season, preparatory (Camp), early In-Season phase and School periods. Participants’ sleep was monitored in the evenings within the period June-October covering the off-season phase where strength and conditioning practices predominated (Off-Season, 24 nights), through the preparatory camp where there was more focus on on-field training (Camp, 27 nights), and into the early parts of the regular season (In-Season, 27 nights). The final phase was when school began in addition to still playing in the latter stages of the regular season (School, 26 nights. Data was retained for analyses if athlete sleep data was present for 3 nights in each phase. This resulted in differing athlete numbers for each phase (Table 1). In total, 580 observations were analysed. During each monitoring period, participants’ daily training output (external training load) for on-field training was also collected in the day prior to the sleep, with on-field training present in all phases. Training schedules were set at the discretion of the team coaches and conditioning staff. Games were scheduled by the NCAA.

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***Procedures***

*Training Schedule*

The training schedule for each phase of the year is depicted in Figure 1. Players resided at their homes for the duration of the study outside of the first week of Camp, where they were in dorm rooms situated close to the host training facility.

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*Sleep/wake assessments*

During the monitoring period, participants wore actigraphs (ActiGraph GT9X Link, Pensacola, FL) on their non-dominant wrist. These devices have been shown to be a valid alternative to polysomnography for measuring sleep in athletes in the field (Sargent, Lastella, Halson, & Roach, 2016). Participants wore the same monitor for the testing period. Data derived from the wrist monitors were used to determine the amount and quality of sleep obtained (Cole-Kripke algorithm within Actigraph software). As per previous research, dependent sleep assessment variables were derived from the activity monitors as:

*Bedtime* (hh:mm): clock 24-hr time at which a participant went to bed to attempt to sleep

*Awake time* (hh:mm): clock 24 hr-time at which a participant got out of bed and stopped attempting to sleep

*Time of sleep onset* (hh:mm): clock 24-hr time that a participant fell asleep at the start of a sleep period

*Sleep latency* (min): the period of time between *Bedtime* and *time of sleep onset*

*Total counts*: the total actigraphy counts summed together for the entire sleep period

*Sleep efficiency* (%): the percentage of time in bed that was spent asleep

*Time in bed* (min): the amount of time spent in bed attempting to sleep between *Bedtime* and *Awake time*

*Total sleep time* (min): the total amount of sleep obtained during a sleep period

*Wake after sleep onset* (min): the amount of time spent awake after sleep has been initiated as a percentage of sleep

*Awakenings* (count): the number of different awakening episodes as scored by the algorithm

*Average Awakening Length* (min): the average length, in minutes, of all awakening episodes

*Movement Index* (%): the percentage of epochs with y-axis counts greater than zero in the sleep period

*Fragmentation Index* (%): the percentage of one minute periods of sleep vs. all periods of sleep during the sleep period

*Sleep Fragmentation Index* (%): the index of restlessness during the sleep period expressed as a percentage (e.g. the higher the index, the more sleep is disrupted)

*External training load*

Players wore an inertial measurement unit during training and match activities (Optimeye S5; Catapult Innovations, Melbourne, Australia). The Optimeye device includes a 10 Hz GPS, a 100 Hz accelerometer and a 100 Hz gyroscope, which have previously been shown to have acceptable reliability and validity during team-sport activity (Nicolella et al. 2018). Devices were inserted into a custom-made pouch and attached between the scapulae of the players’ shoulder pads. Each player used the same device each day to maintain consistency between sessions. Data were uploaded post-session using Catapult’s OpenField 1.11 software (Catapult Innovations, Melbourne, Australia) and collated in Microsoft Excel. Player LoadTM (PL) was calculated for each training session using a customised algorithm within the software provided by the manufacturers (OpenField 1.11 software, Catapult Innovations, Melbourne, Australia). PL was used in preference of GPS derived metrics as some sessions were performed indoors as per previous research (Govus et al. 2018). Briefly, this parameter is collected through tri-axial accelerometers and represents the square root of the sum of the squared instantaneous rate of change in acceleration within the three planes divided by 100 (Catapult Innovations, Melbourne, Australia).

***Statistical Analyses***

All data were checked for normality, before descriptive analyses of sleep behavior were conducted with summary data presented as mean ± standard deviation (SD). The relationships between both season phase and completed training load and each sleep metric were assessed using individual linear mixed models. Differences between season phases were evaluated using the least squares means test, whilst the effect of training load on sleep was assessed using 2 x within-subject SD of the predicted (obtained from a separately constructed, intercept-only reliability model). This method results in the expected change in the outcome measure given a change from a typically low to a typically high value (Hopkins 2014). Effects were standardised using one between-subject SD of the outcome variable, and the likelihood of those effects were interpreted using a magnitude-based inference network. Effects were considered real if the likelihood of the effect being greater than 0.20 exceeded 75%, 95% and 99.5% for *likely*, *very likely* and *almost certainly*, respectively (Batterham and Hopkins 2006; Hopkins 2004). All analyses were performed using R Studio (v 3.4.2).

**Results**

***Sleep variables***

Total minutes in bed were lower during the Camp, In-Season and School phases compared to the Off-season phase (-40±13 min, ES 0.80±0.42; -42±13 min, ES 0.86±0.45; and -23±15 min, ES 0.46±50, respectively; Figure 2). Total sleep time was also shorter in Camp (-41±13 min, ES 0.68±0.36), In-Season (-56±14 min, ES 0.93±0.39) and School (-28±15 min, ES 0.46±0.42) compared to the Off-season phase. Sleep efficiency was worse In-Season compared to Camp (-2.8%±0.8%, ES 0.42±0.10) and Off-season (-3.5%±1.7%, ES 0.53±0.12). Sleep onset latency increased progressively across phases during the year with all phases worsened compared to the Off-Season (-0.76±0.38 min, ES -1.91±0.97; -0.91±0.41, ES -2.31±1.04; -1.67±0.38, ES -4.23±0.95 for Camp, In-Season and School, respectively).

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***External load responses***

Mean PL across phases differed with Off-Season lower than all other phases (-164±36, ES -1.76±0.39; -155±34, ES -1.67±0.37; -133±61, ES -1.43±0.66 for Camp, In-Season and School, respectively; Figure 2).

***Effect of training load (PL) on sleep***

Within phases, the effect of two within-subject SDs of player load on each of the sleep metrics was assessed (Figure 3). There was *almost certainly* a difference in sleep latency during the school phase (ES=4.67±2.03). There was *very likely* a difference in total minutes in bed during the school phase (ES=-0.7±0.61).

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**Discussion**

The present investigation aimed to examine the relationship between objective measures of sleep and external training load in ACF players across different phases of the NCAA D1 season. The main finding of this study was that sleep volume was reduced during periods of intensified training (Camp and In-Season) in ACF players. There were increases in sleep latency during the School phase and reductions in sleep time compared to other times of the year suggesting that increased external loads coincide with periods of reduced sleep volumes, which is concerning given the theoretical need for increased recovery would be higher during these periods of intensified training. Taken collectively, these findings provide important practical considerations for ACF coaches and practitioners when prescribing training and/or recovery.

Due to the combination of academic and athletic requirements, ACF players are hypothesised to be one of the most at risk (healthy) populations for sleep disruption (Lund et al. 2010; Fullagar et al. 2017). In the current study players’ sleep durations (regardless of phase) were all less than 420 min (range ~360-418 min). This would support previous evidence of these students demonstrating poorer patterns of sleep compared to healthy adults (Lund et al. 2010). Indeed, some adolescent athletes sleep 2 h less than recommended daily sleep volumes (Aerenhouts, Zinzen, and Clarys 2011) and elite athletes have been shown to regularly encounter sleep disruption (Juliff, Halson, and Peiffer 2015). In a study of 628 athletes across 29 teams at Stanford University , ~40% of athletes reported obtaining <7 h of sleep on weekdays (Mah et al. 2018). Sleep duration was poorest during Camp and In-Season in our study, which adheres to previous research where sleep has been reported most at risk during intensive training weeks or in-competition (Nimmo and Ekblom 2007). This is concerning given the reported association between sleep loss and injury risk (Luke et al. 2011) and the effect reductions in sleep quantity can have on compromising athletic performance or recovery outcomes (Fullagar, Skorski, et al. 2015; Nédélec et al. 2015; Halson 2014). This may be further exacerbated when training at night (Costa et al. 2018). Furthermore, the present results may represent concerns for the practitioner, since the loads in these two intensified phases may suggest the homeostatic need for recovery sleep would be higher compared to other phases of the season where load is less (Romyn et al. 2015).

The main finding of this study was that sleep volume was reduced during Camp and In-Season. Whilst training load (as measured by PL) may be associated with a negative effect on sleep quantity and/or quality, there may exist alternative sources of poor sleep. In our study PL was associated with a number of sleep parameters including total sleep time, average awakenings and sleep fragmentation index as well prolonging sleep latency during the School phase. (Thornton et al. 2017) also observed reduced sleep volume alongside greater daily training volume and intensity in rugby league players during a two-week high intensity training camp. In a separate study, the same authors found daily total distance and high-speed distance running loads were associated with reduced sleep duration, earlier bed times and a lower sleep efficiency (Thornton et al. 2018). Although we did not collect any markers of fatigue or altered homeostatic state, it is possible that the increase in PL in our study was associated with increases in muscular damage or inflammation, which has been hypothesised to contribute to disrupted sleep (Nédélec et al. 2015; Roth et al. 2017). Given the increase in contact/collision load in the Camp and In-Season periods, this would support previous reports of pain preceding poor night’s sleep (Raymond, Nielsen, and Lavigne 2001); however given the lack of biological/fatigue markers in our study this remains speculative. It should be noted that there is also evidence for improved sleep following increased acceleration and deceleration demands (Thornton et al. 2018), suggesting the homeostatic need for recovery sleep is higher following such events. Thus, it would appear there are particular components of the type of running activity, which may enhance the need for, or disrupt sleep, respectively. Further research, which examines the relationship between the different components of running- or collision-based activities and sleep parameters in American Football, may aid our understanding of the player recovery requirements from which appropriate training methodologies can be developed.

There is previous evidence of differences in sleep parameters with no changes in load. For instance, despite similar match loads (calculated from s-RPE) from day matches and night matches, large reductions in sleep duration were reported in sixteen elite soccer players following night matches compared to day matches (Fullagar et al. 2016). This may suggest that there are particular nuances about the timing of the exercise event (i.e. training or games) which cause sleep disruption outside reasons arising from the exercise load itself. In our study we found that load decreased time in bed during both Camp and School; however there may have been unaccounted factors that may have explained the difference in sleep parameters between phases. For example, in the previous cited soccer example, the most obvious reason for poorer sleep in night matches is the pure extension of a later bedtime caused by the timing of the match. Alternatively, some athletes report earlier wake times on training days, although there is no difference in sleep volumes (Thornton et al. 2018). In our study athletes rose later in the Off-season, and went to bed earlier, than during Camp with athletes going to bed progressively later across phases with deviation in the direction of change associated with the rise time. These results support the idea that sleep indices are likely dependent on the situational demands and scheduling of the particular sport (Juliff, Halson, and Peiffer 2015; Sargent et al. 2014). For example, swimmers rise earlier and incur shortened sleep durations prior to training days compared to rest days (Sargent, Halson, and Roach 2014). Furthermore, collegiate athletes in their two years of college report high levels of daytime sleepiness, and worsened sleep time has been shown to be associated with increased difficulty in waking up for practice and class (Mah et al. 2018). It is possible that due to the difference in training scheduling times and subsequent activities in our study may have altered players’ sleeping habits; however further research which depicts additional factors which may be responsible for differences in sleep between different stages of the season is required.

Being a student-athlete for an NCAA sanctioned sport also represents a unique set of demands for ACF players. The most obvious combination of demands is when School commences during the mid to latter stages of the In-Season period. Here, players will likely be committed to being present at the football department each day of the week for training, meals, meetings and personal review (e.g. watching film). Thus, when School starts and these players are expected to continue their football commitments there poses risk to mental health and anxiety (Romo 2017; Mann et al. 2016). In our study, sleep onset latency progressively worsened as the year went on, and when accounting for effects of PL on sleep latency, had an *almost certain* increase during the School phase. Furthermore, there was a *likely* reduction in total sleep time. Given that the majority of study in college students is done on computer devices and the combination of mental demands present during the School phase (e.g. learning plays whilst doing homework), it is likely these factors negatively influenced sleep parameters in our cohort (personal communication). Indeed, this would support previous evidence of prolonged sleep onset and reduced sleep durations following extended exposure to electronic devices prior to the commencement of sleep (Bartel, Scheeren, and Gradisar 2018; Brunetti et al. 2016). Furthermore, sleep disorders in collegiate athletes in Japan have been shown to be associated with a number of lifestyle issues such as late bedtimes, early wake-up times, late night part-time employment, use of smartphones, psychological distress and competition activities (i.e. morning practices) (Monma et al. 2018). In addition, collegiate athletes have reported lower sleep qualities on campus compared to travelling for competition (Mah et al. 2018). However, whether this was the case in our cohort remains speculative and further research pertaining to potential underlying causes of extended sleep onset and reduced sleep volume in ACF players is required. It should also be noted that although some of the results in our study report effects (e.g. large ES - sleep onset latency), it is debatable whether such effects are practically meaningful (i.e. 90 sec - sleep onset latency).

One of the limitations of the present study was the use of actigraphy for sleep. Such a measure makes it difficult to estimate sleep quantity and quality compared to the ‘gold standard’ polysomnography (PSG). Indeed, previous work has shown actigraphy measurements (i.e. sleep onset latency) show heightened error when compared to PSG (Fuller et al. 2017; Farabi, Quinn, and Carley 2017). However, given the need for practical measurements in the field, actigraphy was deemed necessary to obtain objective measures of sleep. Although done across different stages of the calendar year, the present study entailed a fairly short sampling period within each period (3 d). Due to large variation in day to day training (in and across phases), this may limit the true inference of training on sleep and also introduce potential bias with accurate representation of season phase. Nonetheless, this sampling period is similar to previous research (Leeder et al. 2012) and when combined across phases, is still longer than other reported actigraphy data studies (Fullagar, Skorski, et al. 2015; Leeder et al. 2012). Given the numerous components of PL (Nicolella et al. 2018), we acknowledge this makes it difficult to extrapolate our results with regard to the effect of different aspects of running and mechanical load, especially across different time points throughout a season where certain aspects of each may be predominant. However, the use of PL is one of the few parameters measured throughout each session as ACF sessions alter in and out doors, limiting the use of global positioning systems parameters (e.g. distance metrics). Furthermore, there were no measures available to quantify weight room load, which fluctuates heavily dependent on the time of the season. Finally, no weight room load, exact practice/training start/finish times, or daily naps data were recorded which limits the inferences of our results.

**Perspective**

The primary findings of this study were that sleep volume in ACF players was reduced during periods of intensified training (Camp and In-Season). In addition, there were increases in sleep latency during the School phase compared to other times of the year. Overall, our results suggest that increased external loads result in reduced sleep time, which is concerning given the theoretical need for increased recovery would be presumably be higher during these periods of intensified training; however other causes of this sleep disruption shouldn’t be discounted. In summary, these findings provide important practical considerations for ACF coaches and practitioners when prescribing training and/or recovery.

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**Competing interest**

The authors do not have professional relationships with any companies or manufacturers that

will benefit from this study. The authors declare no conflicts of interest.

**FIGURE CAPTIONS:**

**Figure 1:** Yearly overview of typical stages and activities of the calendar year in collegiate American footballers.

**Figure 2:** Sleep parameters across four stages of the calendar year in collegiate American footballers. \*: *likely* \*\*: *very likely* \*\*\*: *almost certainly*; Symbols indicate worsening direction of parameter. Number of awakenings (\* for Season vs Camp and School); Average awakenings (\* for Camp vs Off-season, \*\*\* for Season vs Off-season, \* for School vs Off-season, \*\* for Season vs Camp, \* for Season vs School); Sleep efficiency (\*\*\* for Season vs Off-season and Camp, \* for Season vs School); Sleep onset latency (\*\*\* for School vs all phases, for Camp vs Off-season, and for Season vs Off-season); Movement index (\* for Season vs Off-season and Camp); Player Load (\*\*\* for Off-season vs all phases); Total minutes in bed (\*\*\* for Camp vs Off-season, \*\*\* for Season vs Off-season, \* for School vs Off-season, \* for Season vs School); Total sleep time (\*\* for Camp vs Off-season, \*\*\* for Season vs Off-season, \* for School vs Off-season, \* for Season vs School); Wake after sleep onset (\* for Season vs Off-season and School, \*\* for Season vs Camp).

**Figure 3:** The effect of training load on sleep in collegiate American footballers. \*: likely \*\*: very likely \*\*\*: almost certainly. AveAwake: Average Awakening Length; Efficiency: Sleep efficiency; FraIndex: Fragmentation index; MovtIndex: Movement Index; NoAwake: Number of awakenings; SleepFragIndex: Sleep Fragmentation Index; TMB: Total minutes in bed; TST: Total sleep time; WASO: Wake after sleep onset.

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