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EXAMINATION OF VOLUME AND INTENSITIES OF WEEKDAY PRACTICES AND COMPETITIVE GAMES IN COLLEGIATE FOOTBALL PLAYERS

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EXAMINATION OF VOLUME AND INTENSITIES OF WEEKDAY PRACTICES AND COMPETITIVE GAMES IN COLLEGIATE FOOTBALL PLAYERS

THESIS

A thesis submitted in partial fulfillment of the

requirements for the degree of Master of Science in the

College of Education at the University of Kentucky

By

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ABSTRACT OF THESIS

EXAMINATION OF VOLUME AND INTENSITIES OF WEEKDAY PRACTICES AND COMPETITIVE GAMES IN COLLEGIATE FOOTBALL PLAYERS

The aims of the present study were to characterize the typical volume (total distance) and intensities (high-speed distance >75% of maximum speed for weekday practices, Monday through Friday and competitive games on Saturday; compare the daily practice volume and intensities to competitive games to determine if the targeted volume and intensities are achieved as part of the periodized strategies using GPS software; and examine the relationship among total distance, high-speed distance in the prediction of player-load . Thirty NCAA Division I Football players (187.9 ± 5.5 cm; 107.4 ± 24.6 kg) were monitored using GPS receivers with integrated accelerometers during the 13-week regular season during the 2016 season. Separate one-way repeated measures ANOVAs demonstrated that competitive game loads and intensity were significantly different than weekday practices (p-value $\leq$ 0.05). There were significant differences among weekday practices in terms of overall volume and intensities, however the overall training goals were not met. Stepwise linear regression revealed that total distance is a significant predictor of player load. The results of the present study indicated that total distance, but not high-speed distance, could best be used to describe and track the development of a periodization model for training in Division I Collegiate Football using GPS technologies.

Keywords: GPS, American Football, Periodization, Volume, Intensities

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EXAMINATION OF VOLUME AND INTENSITIES OF WEEKDAY PRACTICES AND COMPETITIVE GAMES IN COLLEGIATE FOOTBALL PLAYERS

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Chapter I

Introduction

Contact sports, such as American football, require repeated, high-intensity, short-duration bouts of exercise and rely on high levels of strength, power, and speed (9, 17, 18). Most (up to 90%) of the adensonsine triphosphate (ATP) regeneration during a football game is provided by the phosphagen energy system, with smaller contributions from the anaerobic glycolytic and aerobic energy systems (9). Knowledge of these metabolic and physical demands is important for strength and conditioning coaches to develop practice schedules for athletes that develop the requisite strength, power, and speed necessary for success in a competitive game. Recently, the use of Global positioning systems (GPS) in team sports has become increasing popular to track the volume and intensity of competitive games and training sessions (1-8,20).

The GPS monitors have been used to quantify objective measures of variables such as total distance covered (in meters, yards, kilometers etc.), the amount of distance covered in a variety of speed zones (meters per second, yards per minute, kilometer per hour etc.), change of direction to the left or right, and the number of accelerations and decelerations (2). In addition to these variables, strength and conditioning coaches have utilized a variable developed by Catapult Innovations (Melbourne, Australia), termed 'player-load'. Player load is defined by Catapult as an accelerometer variable, without units, that captures movement in the three spatial planes of motion. Although player-load has been shown to be reliable (9,10), it is calculated from a proprietary equation and, thus, has not been validated. This lack of validity limits its application to quantify the volume and intensities of practices and games that are necessary to structure a periodized program. The GPS variables, total distance (yards) and high-speed distance (yards per minute at an intensity ≥ 75% maximum speed), however, have quantifiable units that may be used to monitor total volume and intensity, respectively, of practice sessions and games. No previous studies have examined the relationships among total distance, high-speed distance, and player-load or determined which of these variables (total distance and high-speed distance) best predicts player load.

Periodization is defined as a training regimen, in which peak performance is brought about through the potentiation of physiological abilities and the management of fatigue and accommodation. (8,20). Many periodized strategies in team sports incorporate recovery periods that have been shown to improve physiological adaptations during the training process (24,26,27). According to Stone et al. (20), the trade-off between training and recovery is designated by three principle theories, the General Adaptation Syndrome (GAS), Stimulus-Fatigue-Recovery Adaptation Theory (SFRA), and Fitness-Fatigue Paradigm (Fit-Fat). The GAS theory, explains the body's physiological responses to a stress, and suggests that no matter the environmental stressor, the physiological responses are always the same (20). The SFRA theory, suggests that fatigue accumulates in proportion to the strength and duration of a stimulus. In addition to the strength of a stimulus, if a stimulus is not applied with sufficient frequency, detraining (involution), may occur (20). The Fit-Fat theory suggests that an athletes' preparedness is based on the principles of after-training effects of fitness and fatigue. The Fit-Fat theory also assumes that these two training effects demonstrate an inverse relationship rather than a cause and effect relationship as suggested by the GAS and SFRA theories (20). In addition, this theory implies that strategies that maximize fitness and minimize fatigue will have the greatest potential to optimize athlete preparedness (20). The Fit-Fat theory is commonly used to structure a periodized practice plan for team bases sports such as American football (8,20). Utilizing the Fit-Fat theory, strength and conditioning coaches manipulate training volume and intensities throughout a specific training period to avoid fatigue accumulation, which may lead to decreased performance (8,20). Kraemer et al. (15) demonstrated that both starting and non-starting soccer players experienced performance detriments over an 11-week period. These results suggest that since reductions were shown across the entire team instead of the starting players, that performance adaptations may be independent of total match play and that the volume of practice sessions as well as strength and conditioning sessions should be monitored carefully for both starters and non-starters (8,15,20).

Basic in-season periodization techniques are designed to incorporate the theories of GAS, SFRA, and Fit-Fat. In American football, teams will usually have a full week (7 days) before the next competition, with the expectation of bye weeks. It was assumed that competitive games would be characterized by the highest volume and intensities, and the proposed periodized model must be designed to combat these stressors of competitive game play. By utilizing the theory of GAS, practice loads and intensities were designed to oscillate throughout the preparatory week (Monday-Friday) with varying volumes and intensities to allow players enough time between sessions to recover and allow for supercompensation before the next competitive game. To determine what the varying loads and intensities would be, the theory of SFRA was applied. This theory states that fatigue will accumulate in proportion to the strength and duration of a stimulus (i.e., greater the stimulus the greater the fatigue and more time devoted to recovery) (20). In addition, this theory states that if a specific stressor (e.g., maximum speed) is not applied with sufficient frequency, involution/detraining may occur (20). During an in-season period, the goals of the coaching staff were to maintain maximum speed on the playing field. Based on the concepts of residual training effects by Issurin and Lustig (2004), maximum speed has a residual training effect of 5±3 days (20). For this reason, weekly periodized schemes were designed to incorporate loads and intensities that would achieve a game like stimulus within these residual training windows. With a competitive game on Saturday, the next stimuli should be applied no less than two days' post-match and no more than 8 days' post-match (8,20). To allow sufficient recovery, the next game like stimuli were to be applied on Tuesday practices for starting players. For non-starting players, as well as starters that did not meet the game like demand stimuli the day prior, Wednesday served as a second opportunity. To determine the amount of recovery between high loads and intensity, the theory of Fit-Fat was applied to the proposed periodized model. The Fit-Fat paradigm implies that strategies that maximize fitness and minimize fatigue will have the greatest potential to optimize athlete preparedness (20). To achieve this outcome, a proper taper period must be used. The proposed model followed a 2-phase taper created by Bosquet et al. (3). This taper involved a classical reduction in the training volume, followed by a moderate (75-85% of game-like stimulus) increase during the last days of the taper period. With this taper strategy in mind, following a training session of game like stimulus (Tuesday/Wednesday), a reduction in 50% or less of volume and intensity was used on the following day (Thursday). Leading into competition play, intensity increased moderately (Friday). This strategy was used to reduce the athlete's fatigue before the reintroduction of more intense efforts and to prevent staleness during competitive game play. This 2-phase taper was utilized based on the evidence of progressive improvements observed in a pre-event taper conducted by Mujika et al. (2009). This reintroduction of more intense efforts was also constructed two-days after competition play (Monday), following a day of rest. No previous studies, however, have used quantifiable measures of exercise volume and intensity to monitor these periodization techniques. Therefore, the purposes of this study was to: 1) characterize the typical volume (total distance) and intensities (high-speed distance >75% of max speed) for weekday practices, Monday through Friday and competitive games on Saturday; 2) compare the daily (weekdays) practice volume and intensities to competitive games to determine if the target volume and intensities are achieved as part of the periodized strategies using GPS software; and 3) examine the relationship among total distance, high-speed distance, and player-load and determine which of these variables (total distance and high-speed distance) best predicts player load. It was hypothesized that both high-speed distance and total distance will significantly predict player load, with a greater amount of the variance explained by total distance.

Chapter II

Literature Review

Reliability and Validity of Data Collection Systems

(Aughey 2011)

The purpose of this article is to elaborate on the application of Global Positioning System (GPS) technologies to field sports. In addition, this article sought out to discuss the history, reliability, and validity of human locomotion using GPS devices. GPS tracking was made possible through the development of the nuclear magnetic resonance method which lead directly to the creation of atomic clocks, the precise timepieces that form the basis of satellite navigation. If and when at least four satellites are in communication with a GPS receiver, accurate location of the receiver can be triangulated and the displacement of the device can be derived. Once this position is known, the displacement over time can be utilized to calculated velocity of movement which is of upmost interest to sport scientist, coaches, and athletes engaged within teams' sports.

Validation studies for GPS tracking didn't occur until 2009-2010, with studies employing slightly different methodologies and GPS technology being published. The first obstacle was determining the validity of the gold-standard criterion measure that GPS will be compared with. For example, the most popular ways of measuring total distance is through tape measure or trundle wheel, however there is small amounts of error in the way to measure such distances. These small errors were overcome in a study using

VICON as the criterion measure and showed a very low identification error (0.0008%) (20). It has been concluded that the higher sampling rates the more valid GPS monitors become. Currently the most reliable GPS monitors on the market are sampling at a rate of 10 Hz.

In conclusion, the application of GPS technology has revolutionized the body of knowledge around player movements in field based sports. This technology is valid and reliable enough to detect altered running across a match, between matches, between levels of competition and between types of matches.

(Coutts and Duffield 2010)

The aim of this study was to assess the validity of several GPS devices for measuring distance and peak speed during high-intensity intermittent exercise, and the intra-model reliability of GPS devices for measured running speed and distance in team sport athletes. Two moderately trained males each completed eight bouts of a standard circuit that was designed to elicit the movement demands of team sports. This consisted of six laps around a 128.5 m running circuit, which involved walking, jogging, fast running, sprinting and standing still. One minute was allowed to complete each lap. Distance and speed were collected concurrently during each trial at 1 Hz using six different GPS devices. The recorded variables included the total distance covered in each lap, low intensity activity distance, high intensity running distance, and very high-intensity running distance during each bout. These zones were selected as they reflect the zones previously reported in recent time-motion analysis literature in field-based sports. The peak speed was also measured during a 20-m sprint at the start of each lap of the circuit. Actual distance was measured using a measuring tape and sprint performance was measured using timing lights. A One-way ANOVA with Scheffes post hoc testing was used to examine differences in distances and speed measures obtained between different devices and laps.

Mean (± SD) circuit total distance was significantly different between each of the GPS devices ($P<0.001$), however, all devices were within 5 meters of the actual lap distance and had a good level of reliability (coefficient of variation (CV) <5%). The CV for total distance (3.6-7.1%) and peak speed (2.3-5.8%) was good-to-moderate, but poor for high intensity running (11.2-32.4%) and very high intensity running (11.5-30.4%) for all GPS devices. These results show that the GPS devices have an acceptable level of accuracy and reliability for total distance and peak speeds during high-intensity, intermittent exercise, but may not provide reliable measure for higher intensity activities.

(Johnston 2012)

The purpose of this research was to investigate the validity and reliability of 5-Hz global positioning systems (GPS) measuring athlete movement demands including the player load and peak running speed. Nine well-trained male participants volunteered to complete the test. The speed zones and movement demands used in this study were based on previous research. Variables derived from GPS were total distance, average peak speed, player load, and distance covered performing each activity, time spent performing each activity, and number of efforts performed. The TSSC (team sport simulation circuit) was designed to replicate the movement demands encountered by athletes during team sports, including standing, walking, jogging, running, and sprinting along with acceleration and deceleration movements. Criterion measurements were completed via a tape measurer (130.5 m). Each participant was required to complete 10 laps of the TSSC. A paired sample t-test was used to determine the difference between the criterion and GPS scores for total distance and peak speed. The results revealed that GPS was a valid and reliable measure of total distance covered ($p>0.05$, percentage typical error of measurement ([%TEM] <5%) and peak speed ($p>0.05$, %TEM 5-10%). GPS was found to be a reliable measure of player load (% TEM 4.9%) and the distance covered, time spent, and number of efforts performed within certain velocity zones (%TEM <5% to >10%). The level of GPS error was found to increase along with the velocity of exercise. These findings demonstrated that GPS was capable of measuring movement demands performed at velocities $<20\ km\cdot h^{-1}$, whereas more caution should be exercised when analyzing movement demands collected by using GPS velocities

>20km h^{-1}. Higher sampling rates have been shown to show have a greater reliability and validity.

(Gabbett 2012)

The purposes of this study were: 1) to investigate the velocity distribution of elite field sport athletes from 5 sports, to statistically generate velocity ranges that could be consistently used for those sports; and 2) to describe the process undertaken to develop a new definition of a sprint from GPS data that considers both high acceleration and high velocity efforts. Data were collected from men's and women's soccer, men's and women's field hockey, and a professional Australian Rules Football team. Twenty-five data sets representing 5 complete games from 5 individuals were analyzed for the 5 sports (total of 125 data sets). Data were collected at 1 Hz and later downloaded by GPS software packages. Several authors have indicated the accuracy of GPS technology to be very good when measuring the movement demands of athletes. For all individual data sets, average distribution of velocity was calculated for each sport. Decelerations or negative velocities were not included in the analysis. Acceleration data were calculated from velocity data for each set. The results showed similar average velocity distribution for each of the different sports for standing velocities as well as walking velocities, indicating that a large proportion of time was spent standing and walking during play in each of the 5 sports. Velocity differences were reported between men's and women's sports, but not among different sports. The highest 5% of accelerations in each of the recommended velocity ranges were determined from a single soccer player and revealed that the threshold acceleration used to identify a sprint tends to increase with increasing velocity. Based on these results, recommendations about sport-specific velocity ranges to be used in future time-motion studies of field sport athletes should be of interest. Suggestions about sprint definition to be defined as any movement that reaches or exceeds the sprint threshold velocity for at least 1 second and any movement with an acceleration that occurs within the highest 5% of accelerations found in the corresponding velocity range. These results provide strength and conditioning staff with information regarding the high-intensity sprinting demands of field sport athletes, while also providing a novel method of capturing maximal effort, for short duration sprints.

(Jennings, Cormack, Coutts, Boyd, Aughey: 2010)

The purpose of this study was to assess the validity and reliability of distance data measured by global positioning systems (GPS) units sampling at 1 and 5 Hz during movement patterns common to team sports. Twenty elite Australian Football players each wearing two GPS devices (MinimaxX, Catapult) completed straight line movements (10, 20, 40 m) at various speeds (walk, jog, stride, sprint), changes of direction (COD) courses of two different frequencies (gradual and tight), and a team sport running simulation circuit. Position and speed data were collected by the GPS devices at 1 and 5 Hz. Distance validity was assessed using the standard error of the estimate (±90% Confidence intervals [CI]). Reliability was estimated using typical error (TE) ± 90% CI (expressed as coefficient of variation [CV]). Measurement accuracy decreased as speed of locomotion increased in both straight line and the COD courses. Difference between criterion and GPS measured distance ranged from 9.0% to 32.4%. A higher sampling rate improved validity regardless of distance and locomotion in the straight line, COD and simulated running circuit trials. The reliability improved as distance traveled increased but decreased as speed increased. Total distance over the simulated running circuit exhibited the lowest variation (CV 3.6%) while sprinting over 10 m demonstrated the highest (CV 77.2% at 1 Hz). Current GPS systems maybe limited for assessment of short, high speed straight line running and efforts involving change of direction. An increased sample rate improves validity and reliability of GPS devices.

(Johnston 2014)

The purpose of this study was to assess the validity and interunit reliability of 10 Hz (Catapult) and 15 Hz (GPSports) Global Positioning System (GPS) units and to investigate the differences between these units as measures of team sport athlete movement demands.

This study used eight trained male participants to investigate interunit reliability between the 10 Hz and 15 Hz units. Testing was conducted over a two-day period. Participants were required to complete a team sport simulation circuit (TSSC), which enabled the assessment of 10 Hz and 15 Hz GPS units under conditions like team sport matches. The TSSC was like that to assess the validity and reliability of 1 Hz and 5 Hz GPS units. Variables collected from 10 Hz and 15 Hz units included: total distance covered (TD), average peak speed, and the distance covered, time spent, and the number of efforts performed low-speed running (0.00-13.99 km h^{-1}), high-speed running (14.00-19.99 km h^{-1}), and very high-speed running (>20.00 km h^{-1}). A paired samples t-test was used to test the degree of difference between the 10 Hz and the 15 Hz GPS units. Pearson's correlations were also used for validity assessment. Interunit reliability was established using percentage typical error of measurement (%TEM) and intraclass correlations. These results demonstrated that the 10 Hz GPS unites were a valid (p>0.05) and reliable (% TEM =1.3%) measure of total distance. In contrast, the 15 Hz GPS units exhibited lower validity for total distance and average peak speed. As speed of the movement increased the level of error for the 10 Hz and 15 Hz GPS units increased (%TEM = 0.8-19.9). These findings suggested that comparisons should not be undertaken between 10 Hz and 15 Hz GPS units. The 10 Hz GPS units measured movement demands with greater validity and interunit reliability than the 15 Hz units, however, both 10 Hz and 15 Hz units provided the improved measures of movement demands in comparison to 1 Hz and 5 Hz GPS units.

Section Summary:

The purpose of this section was to examine the reliability and validity of GPS monitoring for field sports. Early reliability and validity studies reported that the use of global positioning system (GPS) units were valid and reliable measures of variables such as total distance covered (10), peak speed, low-intensity (0.00-13.99 $km \cdot h^{-1}$) (10), high-speed running (14.00-19.99 $km \cdot h^{-1}$) (10), and very high-speed running (>20.00 $km \cdot h^{-1}$) (10) utilizing sampling rates of 1 Hz and 5 Hz. Caution should be taken, however, when with measurement of movement demands that are greater than 20.00 $km\ h^{-1}$. In addition, 'speed-zones' of low-intensity (0.0-2.4 $m \cdot s^{-1}$), high-intensity (2.5-5.6 $m \cdot s^{-1}$), and very high-intensity running (any movement that reaches or exceeds sprint threshold (5.7 $m \cdot s^{-1}$) for at least one second) were statistically defined by Gabbett at al. (2012) with the use of 5 Hz GPS systems. With improvements in technology, and the increasing popularity of the use of GPS in team field sports, GPS units were later designed to sample at a rate that was two to three times higher frequencies (10 Hz and 15 Hz). The results established by Johnston et al. (2014) illustrated that the use of 10 Hz GPS not only had the highest reliability and validity, but were also shown to be the most accurate for capturing movement demands at very high-intensity running speeds greater than 20.00 $km \cdot h^{-1}$. The evidence of the GPS reliability and validity (2,5,9,10) provides a measurement technique to more accurately define the movement demands of team sports and determine positional requirements for match play. These data may be used to develop strength and conditioning programs designed to meet the specific needs of each position.

Positional Requirements for High Intensity, Intermittent Sports:

(Wellman 2016)

The purpose of this study was to examine the competitive physiological movement demands of NCAA Division I college football players using portable GPS technology during games and to examine positional groups within offensive and defensive teams, to determine if a player's physiological requirements during games are influenced by the playing position. It was hypothesized that there would be positional differences in movement demands of college football players during games. Thirty-three division I football players participated in this study. All participants were required to participate in a minimum of 75% of the total offensive or defensive plays for the GPS data sets to be included in the present study. The GPS data were collected during 12 regular-season NCAA football games, which were 60 minutes in duration, and composed of four 15 minute quarters for 12-13 weeks during the months of September to November. Each individual GPS data set was characterized as either offense or defense, and later divided into positional groups (Wide Receiver (WR), Quarterback (QB), Running Back (RB), Tight End (TE), Offensive Linemen (OL), Defensive Back (DB), Linebacker (LB), Defensive End (DE), Defensive Linemen (DL)). The GPS variables collected included, total, low-intensity, moderate-intensity, high-intensity and sprint distances (m), maximal velocity achieved ($km \cdot h^{-1}$), and counts of sprint, acceleration and deceleration efforts. These GPS variables were sampled at a frequency of 15 Hz and accelerometer data at 100 Hz. All GPS variables from the present study were presented as descriptive statistics, mean± SD. A one-way ANOVA was used to examine potential positional group differences, with follow-up Bonferroni correct pairwise comparisons. For both offensive and defensive teams, significant ($p \leq 0.05$) differences were found among positional groups for game physical performance requirements. These results further identified that wide receivers (WRs) and defensive backs (DBs) completed significantly ($p \leq 0.05$) greater total distance, high-intensity running, sprint distance, and high-intensity acceleration and deceleration efforts than their respective offensive and defensive positional groups. The results of the present study provided novel insight into position-specific physical demands of NCAA Division I football games. These data may provide physical performance staff with information that may be used to design training programs specific to the demands of each position group to prepare athletes for the physical demands of games.

(DeMartini 2011)

The purpose of this study was to identify the physical demands, as recorded by a GPS device, imposed on Division I football players during preseason training in hot (28.75 ± 2.11 °C) conditions. Forty-nine male football players participated in this study. All playing positions were included, except for place kickers and punters due to limited physical activity required for these positions during practice. The participants were divided into 2 groups: Linemen (L) and Non-linemen – and in a separate analysis - Starters (NL) and Non-starters. The linemen included the positions of defensive end, defensive tackle, offensive tackle, offensive guard, center, and tight end. The non-linemen included the positions of cornerback, free safety, strong safety, outside linebacker, middle linebacker, wide receiver, quarterback, full back, and running back. All the subjects were members of the football team and participated in the first 8 days of the preseason practices. Each practice began with a self-directed warm-up and team stretch, followed by a segment of position drills and ended with a segment of team drills. The subjects were fitted with a GPS device and heart rate (HR) monitor prior to each practice. The GPS and HR data were continuously recorded for the duration of each practice session. The GPS device collected data related to the physical components of player movements such as distance covered, velocity and heart rate. The data were recorded for 1 practice session during the first 8 days of preseason football practice. Core body temperature was recorded via ingestible thermistor. The total distance covered (3,532 ± 943 vs. 2,573 ± 489m; p=0.001) and HRmax (201 ± 9 vs. 194 ± 11 b•min^{-1}; p = 0.025) were significantly greater in NL compared with that in L the group. In addition, the NL group spent more time ($p<0.0001$) and coved more distance ($p=0.002$) at higher velocities than the L group. Furthermore, the S obtained higher velocities ($p = 0.008$, $p = 0.031$) than NS. Given demands of their playing positions, the NL group was required to cover more distance at higher velocities resulting in greater HRmax than the L group. The L group engaged in more isometric work than NL, which can be seen by the majority of distance covered in zone 1 (0.0-1.0 km h^{-1}) and zone 2 (1.1-6.0 km h^{-1}) when compared to NL. This is likely due to the nature of the Linemen position which consists mostly of pass/run blocking, which occurs within a few meters. Also, the average heart rate for the practice between NL and L were not statistically different from one another. Given that NL ran more distance than L, the L group appeared to work in a more anaerobic HR zone than NL due to the specific nature of the position. However, because the HR results contain values that are irrespective of time between plays, this analysis could not be verified. The results of this study showed there was a distinct difference in positional requirements between L and NL groups in terms of distance covered and velocities achieved. In addition, the players exposed to similar practice demands provide similar work output during preseason practice sessions regardless of their playing status.

(Cunniffe 2009)

The aim of this pilot study was to gather information on rugby union forward and back play at the elite level and demonstrate the potential use of GPS technology in the assessment of the games' physiological demands. It should be noted that this study focuses on a small subject number, with a goal to provide insight into the contemporary demands of rugby union with an additional focus on future research. Data were obtained from 3 home team players, which included 1 back (out-half) and 2 forwards (back row and lock). The players were asked to wear an individual GPS unit between their shoulder blades in the upper thoracic-spine region. The players also wore a heart rate monitor to incorporate heart rate data. GPS data was recorded at 1 Hz and accelerometer data at 100 Hz. HR data were categorized into 6 zones based on each player's known maximum HR monitored using an incremental treadmill running test. Frequency and duration of locomotor efforts were evaluated from the time spent in 6 player speed zones (standing and walking, jogging, cruising, striding, high-intensity running, and sprinting). These zones were later categorized into low-intensity activity and moderate- and high-intensity activity. Body load was another variable used by calculation through the system software. Due to the small sample size and nature of the study, descriptive data were only presented for each subject for the measured variables and presented as the mean and standard deviations. These data revealed that players covered on average 6,953 m during play (83 minutes). Of this total distance, 37% (2,800 m) was spent standing and walking, 27% (1,900 m) jogging, 10% (700 m) cruising, 14% (990 m) striding, 5% (320 m) high-intensity running, and 6% (420 m) sprinting. Greater running distances were observed for both players (6.7% back; 10% forward) in the second half of the game. Positional data revealed that the back performed a greater number of sprints (>20 km•h^{-1}) than the forward (34 vs. 19) during the game. The forward position entered the lower speed zone (6-12 km•h^{-1}) on a greater number of occasions that the back (315 vs. 229) but spent less time standing and walking (66.5 vs 77.8%). The current study provided insight into the intense and physical nature of elite rugby using “on field” assessment of physical exertion. Future use of this technology may help practitioners in design and implementation of individual position-specific training programs.

(Wisbey, Montgomery et al. 2010)

The aim of this study was to describe the movement patterns of nomadic players, forwards and defenders for Australian football league (AFL) players. A secondary aim was to compare 2008 game demands with the 2005, 2006, and 2007 seasons to assess the changes in the physical demands that rule and tactical changes have had, and evaluate differences in playing requirements between Australian Football League venues to determine if different sized grounds have an impact on player demands. Elite AFL footballer players (n= 179) from 8 of the 16 AFL clubs were tracked using GPS devices during the 2008 AFL Season. The players were assigned to three major positional groups nominated by their respective clubs (fixed forward, nomadic, or fixed defender). Each player was fitted with an individual GPS device, which captured data at 1 Hz throughout the duration of each game. These data were collected during games and analyzed using computer software after each match. The non-playing periods (quarter breaks and interchange periods) were omitted. The extracted data included total distance (km), time in various speed zones (Standing or walking (≥ 8 $km \cdot h^{-1}$), Jogging (8-12 $km \cdot h^{-1}$), Moderate-Intensity running (12-16 $km \cdot h^{-1}$), High-Intensity running (16-18 $km \cdot h^{-1}$), Sprinting (≤18.1 $km \cdot h^{-1}$)) maximum speed, number of surges, accelerations, longest continuous efforts, and a derived exertion index representing player intensity. Comparisons of variables between positions and years was performed using a one-way ANOVA with Bonferroni post hoc comparison. A zero-order correlation was used to assess the relationships among variables. In addition, the magnitudes of the effect sizes were assessed. The results demonstrated that nomadic players covered per

game 3.4% more total distance (km), had 4.8% less playing time (min), a 17% higher exertion index (per min), and 23% more-time running >18 $km \cdot h^{-1}$ than forwards and defenders (all $p < 0.05$). Physical demands were substantially higher in the 2008 season compared with 2005 with an 8.4% increase in mean speed, a 14% increase in intensity (exertion index), and a 9.0% decrease in playing time (all $p<0.05$). The nomadic players in the AFL worked substantially harder than forwards and defenders by covering more ground and at higher running intensities. The GPS technology appeared to have superseded traditional manually coded time-motion analysis and demonstrates the physical demands of positions as well as the increasing intensity of AFL match play.

(Reardon, Tobin et al. 2015)

The purpose of this study was to compare and contrast the high-speed running demands of professional rugby union when utilizing relative or individualized (IND) speed zones versus the absolute (ABS) defult settings of the GPS manufacturer. It was hypothesized that with the utilization of GPS technology sampling at 10 Hz, combined with reporting on a large sample of players, and games, with inclusion of individualized speed zones will garner more applicable and reliable data on the game related to high speed running demands of professional rugby union. Thirty-six elite professional plyers volunteered to participate in the study. GPS units were switched on 10 minutes prior to the game to ensure a full high quality satellite signal and after match play, data were downloaded to a laptop and analyzed with Sprint 5.1 software. GPS files were only included in statistical analysis if a player had participated for at least the average duration for his position. Total distance (m) and total distance relative to playing time ($m\cdot min^{-1}$) was calculated for each data file. Maximum velocity (Vmax) of each participant was established at the end of the data collection period from analyzing all training and playing datat throughout the season. This included speed training sessions. Relative or individualized speed zones were retrospectively applied to all game data with knowledge of maximum velocity achieved for each participant during the season. Lower threshold of the high speed running (HSR) zone used by the GPS supplier to classify HSR was 5 $m\cdot s^{-1,}$ which has been used in classifying high intensity running in GPS based ruby league studies. To calculate an indiviaual percentage of maximum velocity to classify the individual lower threshold for high speed running (HSR), the arbitrary 5 $m\cdot s^{-1}$ was applied to the mean Vmax of the participants mean velocity of the positional group providing the following formula:

$$\frac{5\ m \cdot s^{-1}}{Vmax\ positional\ mean}$$

As such the individual or relative lower threshold for HSR was set at 60% Vmax. The results of this study indicate that application of individualized speed zones results in a significant shift in the interpretation of the HSR demands of both forwards and back and positional sub-categories therein. When considereing the use of an absolute in comparison to an dindividualsed HSR threshold, there was a significant underestimation for forwards of HSR distance (HSRD) (absoulute = 269 ±172.02, individualized = 354.72 ± 99.22, p <0.001) HSR% (absoulute = 5.15 ±3.18, individualized = 7.06 ± 2.48, p<0.001) and HSR efforts (HSRE) (absolute = 18.81 ± 12.25; individualized = 24.78 ±8.30, p,0.001). In contrast, there was a significant overestimation of the same HSR metrics for backs with the use of an absolute threshold (HSRD absolute = 697.79 ±198.11, individualized = 570.02 ± 171.14, p <0.001; HSR% absolute = 10.85±2.82, individualized =8.95±2.76, p <0.001; HSRE absolute = 41.55±111.25; individualized = 34.54±9.24, p <0.001). The results of the present study indicated that although the use of an individualized HSR threshold improves the interpretation of the HSR demands on positional basis, inter-individual variability in maximum velocity within positional sub-categories means that players need to be considered on an individual basis to accurately gauge the HSR demands of rugby union.

Section Summary:

The studies presented within this section (4,5,14,17,18) showed the utilization of GPS technology in field sports can identify distinct differences among playing positions within various sports (e.g., football, rugby, etc.). Currently, there are only two studies (5,16) that have examined the different positional demands in collegiate football. Specifically, it appeared that non-linemen coved more distance and moved at higher velocities when compared with linemen. These results are consistent for game data when the positions are broken down into specific positions (Wellman et al. 2016). In collegiate football, wide receivers, defensive backs and linebackers covered the more high-intensity distance, when compared to other playing positions. Cunniffe et al. (2009) showed similar results with rugby union players. When comparing backs to forwards, forwards covered more high intensity distances than backs, which showed a positional demand of game play in union rugby using GPS. Furthermore, Wisbey et al. (2010), showed similar findings in AFL match play across four years from 8 of 16 clubs. The authors (Wisbey et al. 2010) reported significant differences in the total distance and total high intensity distance covered between forwards and defenders. It was also reported (Wisbey et al. 2010) that the intensity of AFL matches had increased from 2005 to 2008 with respect to the amount of sprinting distance covered. These findings suggested that players were faster, and the sport was more intense in the 2008 season, when compared to the 2005 season. Lastly, Reardon, Tobin et al. (2015) deomonstrated the use of calcuation of indivudualzed speed zone to accuratley calculate high speed running distances for rugby union players. In all previous studies (4,5,17,18) HSR zones were set at an arbutrarity setting provided by the GPS manufactiors. In the study contuced by Reardon et al. (2015), the show that the pre-set running zones tend to over estimate the running zones when compared to zones that were individualy calcualted. In conclusion, the results from these studies (4,5,17,18) showed there are specific positional requirement demands for different sports. Some positions, such as Wide receivers, Defensive Backs, Running Back or linebackers, demanded more high speed running, while others demonstrated more low- to – moderate intensity distance covered. Thus, these findings may be used to design structured, periodized training programs to meet the specific positional demands within each sport.

Physiological Demands and Responses for High-Intensity, Interment Sport:

(Hoffman 2008)

The focus of this commentary was to provide some insight on the research on American football and to share some of the College of New Jersey's research experience with American Football. To date, our basic understanding of the physiological demands of this sport is primarily based upon empirical observation and deduction. There have been only limited attempts to examine the stresses placed upon football players during an acute competition or competitive season. It has been noticed that each position has specific responsibilities and the demands between each player and position are significantly different (i.e. wide receiver compared to defensive linemen). It has been suggested that the anaerobic energy system is the principle energy system responsible for providing energy to the body during a game of football (6). These authors suggest that up to 90% of the energy production during a football game is provided for by the phosphagen energy system, while the remaining energy production is the result of the glycolytic energy system (6). The authors (Rhea, 2006) reported results from a study that examined the average time of a series of plays for a division III football game and found that there was an average of 14.4 offensive series, with an average of 4.6 plays per series when compared to NFL which has approximately one more play per series than reported for college football games. It was also reported that a recent study examined physiological, hormonal, and biochemical changes during a competitive football game. When comparing starters to non-starters, a complete season of football caused minimal disruptions to adrenal-testicular axis in these athletes. There were notable increases in creatine kinase concentrations at the end of training camp, which later returned to baseline levels by the first month of the season and remained at these levels the rest of the season. The utilization of sport science to maximize the performance ability of American football players is still lacking tremendously. The development of a sport science program could potentially provide a significant stimulus in achieving each player's potential and assist in understanding the specific demands of this sport.

(Rhea 2006)

The purpose of this observational research study was to identify exercise to recovery relationships, as well as descriptive information about other physiological demands, at 3 different levels of play in American football: high school, college, and professional.

A total of 30 football games (10 at each level) were videotaped and portions (minimum of 4 offensive and defensive series) of each game were timed by a stopwatch. Exercise, length of each play, was determined by timing game segments from the snap of the ball to the whistle signaling the end of the play. Recovery, time between plays, was determined by timing game segments from the whistle ending a play, until the snap of the ball for the next play. This was done for each segment of the game as well as documentation of play type: run, pass, punt, or kickoff. Field goals were omitted from the study, due to the short nature of the play. Stoppage times were also included in the recovery time potion of the analysis. Descriptive statistics were then calculated for each phase of the game. The resultant data demonstrated that differences occurred at each level of play for the variables observed. High school plays lasted, on average, 5.6 ± 2.0 seconds and were slightly longer than college (+0.47 seconds) and professional (+0.44 seconds) plays. The average time for recovery between plays was longest in the NFL games (112.59 ± 70.48 minutes) and shortest in high school (81.75 ± 35.81). On average, the work to recovery ratio was most strenuous in high school (1:5.5), college (1:6.1), and NFL (1:6.2), respectively. Differences in the identified competitive conditions, although slight, do exist among high school, collegiate, and professional football. To design specific metabolic training programs for American football, coaches should consider the identified models. Exercise to rest ratios and volume of work performed in a training session should be designed to ensure that players are preparing specifically for identified game conditions. This review demonstrated that the specific work to rest ratios of high school, collegiate and professional football exhibit those properties of anaerobic exercise and strength and conditioning coaches should utilize this information for programing of specific demands in training.

(Kraemer 2013)

The purpose of this study was to track creatine kinase (CK) and serum cortisol over an American college football season starting with the preseason practice to observe their progession over time. This information would provide strength and conditioning staff important information for their program management regarding muscle damage and the stress response. Twenty-two National Collegiate Athletic Association Division I football players (age: 20.4 +/- 1.1 years, height: 188.27 +/- 8.3 cm, weight: 115.8 +/- 29.7 kg) volunteered to participate in this study. Each of the players had participated in the summer strength and conditioning supervised program. Resting blood samples were obtained just before the start of preseason practice (T-1), 2 weeks later (T-2), and the day after game 2 (T-3), game 4 (T-4), game 6 (T-5), and game 9 (T-6) of a 12-game season. Creatine kinase, cortisol, and testosterone were assayed at each time point. No significant changes in CK concentrations were observed over the season with peak values of each range ≤ 1,070.0 IU.L^{-1}, but the largest range was observed at T-6 after game 9 (119-2,834 IU.L^{-1}. The analysis of covariance analysis demonstrated that the number of plays in the ninth game (T-6) explained the magnitude of the changes in CK. No changes in serum cortisol concentrations were observed yet, again large variations existed with peak values of each range ≤465.0 nmol.L^{-1}. Clinical chemistries showed various significant changes from T-1, but none were considered clinically relevant changes for any player over the time course of the study. In conclusion, the strength and conditioning program before preseason camp or the structure of summer camp practices and the in-season strength and conditioning appeared to mute muscle damage and the stress response of cortisol. These data demonstrated that changes in muscle damage and adrenal cortical stress over the season are minimal, yet large individual variations was observed. Management of these variables appears to be related to optimal strength and conditioning and sports medicine programs.

(McLellan 2010)

The aims of the present study were to: 1) examine the player-movement patterns to determine total distance covered during competitive Rugby League match play using GPS; and 2) examine pre, during and post-match creatine kinase (CK) and endocrine responses to competitive Rugby League match play. It was hypothesized that Rugby League match play will result in substantial skeletal-muscle damage and considerable elevation in stress hormone levels post-match. The simultaneous examination of GPS performance data, CK concentration [CK], salivary cortisol concentration ([sCort]), and salivary testosterone concentration ([sTest]) provided a more detailed and specific analysis of the demands of Rugby league match play. GPS technology was used to examine the independent variables of player-movement characteristics, which included variables such as total distance and speed characteristics (velocity zones 1-6-based off previous studies (Cunniffie,2009 Wellmen, 2016)) and was sampled at a rate of 5 Hz. To examine the acute and short-term post-match response of the dependent variables, [sCort], [sTest], and [CK] were measured via saliva and blood samples 24 hours' pre-match; 30 minutes' pre-match; within 30 minutes' post-match; and at 24, 48, 72, 96, and 120 hours' post-match. Seventeen elite male Rugby League players volunteered to participate in the study. Data were collected during a single game of Rugby League play with all participants completing a minimum of 30 minutes of match play. Log transformation was applied to the endocrine data to normalize the distribution and reduce non-uniformity bias. Changes in hormonal concentrations were analyzed using a one-way repeated measures analysis of variance. Significant differences were identified via a Bonferroni post hoc test with an alpha level set at $p \leq 0.05$. The correlation between peak changes in endocrine measures and GPS variables was analyzed using the Pearson product-moment correlation coefficient. Backs and forwards traveled distances 5,747 ± 1,095 and 4,774 ± 1,186 m, respectively throughout the match. Cortisol and CK increased significantly ($p<0.05$) from 30 minutes' pre-match to 30 minutes' post-match. CK increased significantly ($p<0.05$) post-match, with peak [CK] measured 24 hours' post-match (889.25±238.27 UL^{-1}). Cortisol displayed a clear pattern of response with significant ($p<0.05$) elevations up to 24 hours' post-match, compared with 24 hours' pre-match. The GPS technology successfully provided data on player-movement patterns during competitive rugby league match play. Creatine Kinase and endocrine profiles identified acute muscle damage and a catabolic state associated with match play. A return to a normal testosterone: cortisol ratio within 48 hours' post-match indicated that a minimum of 48 hours is required for endocrine homeostasis post-competition. Creatine kinase remained elevated despite 120 hours' recovery post-match. These results illustrate that a prolonged period of at least 5 days of modified activity is required to achieve full recovery after muscle damage during competitive Rugby League match play.

(Gilbert 1981)

The aim of this study was to examine the cardiovascular (heart rate: HR) demands of practice sessions and game situations of professional football players using telemetry. A stress test (maximal graded exercise test: GXT) to determine maximum aerobic capacity was given to players on a professional football team as part of a comprehensive preseason physical examination. Selection was based on performance on the aerobic test and position played, with a range of aerobic capacities and positions chosen. A battery-powered transmitter was padded and fixed rigidly to the exterior of the shoulder pads located above the scapula. Two adhesive electrodes were placed over the distal right clavicle and left sixth rib on the maxillary line. Temperature and relative humidity were measured before and after each 90-minute preseason workout. Descriptive statistics were taken for each player for average heart rate. The results showed that the maximum HR's achieved during the GXT for the defensive backs, running backs, linebackers, defensive tackles, and offensive tackles were 187 $b \cdot min^{-1}$, 195 $b \cdot min^{-1}$, 172 $b \cdot min^{-1}$, 189 $b \cdot min^{-1}$, and 180 $b \cdot min^{-1}$, respectively. The $\dot{V}O_2$ max results indicated the defensive backs had the lowest oxygen consumption (39.4 $ml \cdot kg^{-1} \cdot min^{-1}$) and the linebackers had the highest (49.2 $ml \cdot kg^{-1} \cdot min^{-1}$). The HR responses were observed during several activities for each position such as making a tackle, running with the ball, catching the ball, and pushing blocking a sled or opponent. The results were analyzed in two case studies: case study 1 involved the running back position, and case study 2 involved the defensive tackle position. There was no clear indication as to why these two positions were selected for further analysis. In the first case, this subject was a veteran player that displayed a great deal of fitness capabilities indicated that the subject's heart rate rarely exceeded 140 beats per minute (bpm). During one 15-minute period, this subjects' HR was ranged between 153-200 bpm (77-100% HRmax). It was also noted that this player's peak oxygen consumption was at 46.7 $ml \cdot kg^{-1} \cdot min^{-1}$ at a HR of 195 bpm. In the second case, this subject was chosen for two reasons. First, this subject demonstrated a higher average HR than most of the other players throughout the duration of practice sessions and this players' fitness level which was examined to be 36.6 $ml \cdot kg^{-1} \cdot min^{-1}$. Secondly, while monitoring this player over 90 extra systoles were noted. This usually occurred at rates below 160 bpm and appeared immediately pending any sort of contact. These contractions appeared to be originated from the ventricular region. The results of the maximal oxygen consumption test demonstrate that American football players (regardless the position) do not receive enough aerobic conditioning throughout a practice session as this has been shown to serve not only as a fitness marker, but also as a protective mechanism against injury. Through telemetry, this study showed that the game of football is played at an anaerobic level with periods of aerobic plays.

(Kraemer, French et al. 2004)

The purpose of this study was to investigate the physiological and performance changes that take place over a Big Ten season in college soccer players. Researchers wanted to determine how these players adapted to the effects of conditioning, practice, and high level competition over an entire season. Researchers were specifically interested in determining whether differences existed between starters and non-starters on a collegiate soccer team. Twenty-five male collegiate soccer players were studied throughout a season (11 weeks) to investigate the effects of long-term training and competition. Subjects were grouped as starters (n=11) and non-starters (n=14). Measures of physical performance, body composition, and hormonal concentrations (testosterone [T] and cortisol [C]) were assessed preseason (T1) and 5 times throughout the season (T2-T6). Starters and non-starters participated in 83.06% and 16.95% of total game time, respectively. Non-starters had a significant increase (+1.6%) in body fat at T6 compared to T1. Isokinetic strength of the knee extensors (1.05 rad/sec^{-1}) significantly decreased in both starters (12%) and non-starters (-10%; $p<0.05$) at T6. Significant decrements in sprint speed (+4.3%) and vertical jump (-13.8%) were found at T5 in starters only. Through within normal ranges (10.4-41.6 nmol/L), concentrations of T at T1 were low for both groups, but increased significantly by T6. Concentrations of C were elevated in both groups, with concentrations at the high end of the normal range at T1 and T4 in non-starters and T4 in starters, with both groups remaining elevated at T6. Data indicated that players entering the season with low circulating concentration of T and elevated levels of C can experience reduction in performance during a season, with performance decrements exacerbated in starters over non-starters. Soccer players should therefore have a planned program of conditioning that does not result in an acute overtraining phenomenon prior to preseason. The detrimental effects of inappropriate training do not appear to be unloaded during the season and catabolic activities can predominate.

Section Summary:

The purpose of this section was to describe the physiological demands and responses of the high intensity, intermittent field sports including American football and rugby. Due to the fast-past nature and highly aggressive style of play of Rugby League match play, comparisons were made between rugby and football to illustrate similarities in the physiological responses of both sports. Hoffman et al. (2008), Rhea et al. (2009), and Kraemer et al. (2010) examined the demands of American football and described the physiological responses of the sport. It was reported (Rhea et al. 2009) that, due to the high-intense nature of the sport, the phosphagen system was the primary energy system utilized during competition, with an increased reliance on the glycolytic system as the competition progressed. It was also observed that the time of each play differed among competition levels (high school, college, professional), with high school plays taking the longest amount of time (5.6 seconds) and professional football least. Regardless of these differences in the average time per play, and amount of rest time per play, the phospogen system was still the preferred energy system among all levels of football. In addition, muscle damage and exercise stress responses were examined. Kraemer et al. (2010) showed that creatine kinase response remained elevated up to 48 hours' post-match play along with increases in concentrations of testosterone as well as cortisol in elite rugby play. The response for these hormone levels took ~ 5 days to return to baseline values, with altered training days in between. These results were consistent with those found by McLellan et al. (2010) that looked at creatine kinase concentration in elite ruby play. Lastly, Gilbert et al. (1981) showed that in American football, although match play results in an average HR that exceeds 150 bpm, players of differing positions demonstrate different HR responses and that not enough players get aerobic stimulus in their training. In conclusion, the results from the articles (8,9,13,14,16) in this section demonstrated that football is a sport characterized by high-intensity bouts of exercise that require a high level of strength, power, speed, and agility. Thus, due to the nature of the game, the primary energy system utilized is the phosogen system. Furthermore, due to the aggressive play of football, muscle damage can occur and if not monitored properly, may lead to overtraining.

Periodized Strategies

(Peterson 2004)

The purpose of this investigation was to identify a specific does-response relationship for intensity, frequency, and volume of training and the resultant strength increases by calculating the magnitude of gains elicited by various protocols in collegiate, professional and elite athletic populations. Literature searchers were performed for published studies that included strength measurements before and after strength training intervention programs among competitive athletes. A total of 37 studies were read and coded for the following variables: descriptive information, frequency of training, mean training intensity, number of sets performed, use of creatine, training to failure, and periodization of the training program. Coder drift was assessed by randomly selecting 10 studies for recoding by a separate investigator. Pre/post effect sizes, representing a standardized mean difference, were calculated and a 1-way ANOVA was used to examine differences in effect sizes by variable and training protocol with a level of significance set at $p \leq 0.05$. The effect size data demonstrated that maximal strength gains were elicited among athletes who train at a mean training intensity of 85% of 1 repetition maximum (1RM), 2 days per week, and with a mean training volume of 8 sets per muscle group. The current data exhibit different dose-response trends than previous meta-analytical investigations with trained and untrained non-athletes. These results demonstrated does-response trends for maximal strength gains in athletes and may be directly used in strength and conditioning venues to optimize training efficiency and effectiveness.

(Baker 2001)

The purpose of this study is to report on maximum strength and power levels in professional and college-aged rugby league football players throughout an entire in-season period.

Fourteen professional nation rugby league (NRL) and fifteen college-aged rugby (CRL) league football players participated in this study. Maximum strength was assessed using the 1 repetition maximum bench press (1 RM BP), maximal average power output (Pmax) was assessed utilizing the plyometric power system, Lower-body power was assessed during jump squats (JS Pmax) with resistances of 40, 60, 80 and 100 kg, and lastly upper body power output (BT Pmax) was assessed during flat bench press throws with resistances of 40, 50, 60, 70 and 80 kg. Testing occurred upon completion of preseason training (Pre) and served as baseline values. Groups were tested again at weeks 9 and 19 of the season. Prior to preseason training CRL had 16 weeks and NRL had 8 weeks of a periodized concurrent resistance program. During the in-season period, resistance training was reduced to 2 whole-body sessions per week, as well as conditioning reductions to 2-3 high intensity, 20-30 minute sessions per week. Skill and team practice sessions, which also have an inherently high degree of energy-system conditioning stimulus were carried out 3-5 times per week for approximately 60 minutes each session. Results from 1 RM BP, PT Pmax, and JS Pmax were compared using a repeated measure 1-way ANOVA to determine if any of the in-season tests differed from those of the end of preseason baseline scores or to each other. Pearson's moment correlations were used to determine the strength of relationships between variables.

The results showed for the NRL group, maximal upper-body strength and power were maintained at preseason levels across the entire season. Lower-body maximal power was also unchanged between the preseason and week 29 test. For the CRL group, 1 RM BP improved significantly by 4.9% from the Pretest to week 9 testing. This measurement remained unchanged until the week 19 test. JS Pmax was unchanged between each test occasion for the SRL group. The fact that no reductions in any tests for either group occurred may be due to the periodization, sequencing, and timing of training sessions, as well as the overall periodization of total training volume.

(Hulin, Gabbett et al. 2016)

The purpose of this study was to investigate whether acute workload (1-week total distance) and chronic workload (4-week average acute workload) predict injury in elite rugby league players. Data were collected from fifty-three elite rugby league players over the course of two-seasons. The ‘acute: chronic workload ratio’ was calculated by dividing acute workload by chronic workload. A ratio value of greater than 1 represented an acute workload greater than the chronic workload. All workload data were classified into discrete ranges by calculation of z-scores. Injury was defined as any time-loss injury that resulted in a player being unable to complete full training or missing match time. Data were categorized into weekly blocks from Monday to Sunday. One-week total distance represented acute workload. Chronic workload was calculated as the 4-week rolling average acute workload. Binary logistic regression model with injury/no injury were calculated to determine the relative risk of soft-tissue injury when acute: chronic workload exceed threshold values. Compared with all other ratios, a very-high acute: chronic workload ratio (≥2.11) demonstrated the greatest risk of injury in the current week (16.7% injury risk) and subsequent week (11.8% injury risk). High chronic workload (>16,095 m) combined with a very-high 2-week average acute: chronic workload ratio (≥1.54) was associated with the greatest risk of injury (28.6% injury risk). High chronic workload combined with a moderate workload ratio (1.02-1.18) had a smaller risk of injury than low chronic workload combined with several workload ratios (relative risk range from 0.3 to 0.7x/1.4 to 4.4; likelihood range= 89-94%).Higher workloads can have either positive or negative influences on injury risk in elite rugby league players. Specifically, compared with players who have a low chronic workload, players with a high chronic workload are more resistant to injury with moderate-low through moderate-high (0.85-1.35) acute: chronic workload ratios and less resistant to injury when subjected to ‘spikes’ in acute workload.

(Bosquet, Montpetit et al. 2007)

The purpose of this meta-analysis was to assess the effects of alterations in taper components on performance in competitive athletes. Six databases were searched using relevant terms and strategies. Criteria for study inclusion were that participants must be competitive athletes, a tapering intervention must be employed providing details about the procedures used to decrease the training load, use of actual competition or field-based criterion performance, and all necessary data was used to calculate effect sizes. Twenty-seven of 182 potential studies met these criteria and were included in the analysis. The dependent variable was performance, and the independent variables were the decrease in training intensity, volume, and frequency, as well as the pattern of the taper and duration. Pre-post taper standardized mean differences in performance were calculated and weighted according to the within-group heterogeneity to develop and overall effect.

Results demonstrated that the optimal strategy to optimize performance is a tapering intervention of a two-week duration (ES = 0.59 ± 0.33, P <0.001), where the training volume is exponentially decreased by 41-60% (ES = 0.72 ± 0.36), P <0.001), without any modification of either training intensity (ES – 0.33 ± 0.14, P<0.001) or frequency (ES = 0.35 ± 0.17, P<0.001). These findings illustrate the point that a 2 week taper during which training volume is exponentially reduced by 41-60% seems to be the most efficient strategy to maximize performance gains. This meta-analysis provides a framework that can be useful for athletes, coaches, and sport scientist to optimize their tapering strategies in periodized models.

(Gamble 2006)

This article serves to provide practical suggestions to address the considerations of periodization strategies in training for different phases of physical preparation for team sport athletes. Periodization offers a framework for planned and systemic variation of training parameters, in a way that directs physiological adaptations to the training goals required of the sport (6,14,28,29,34,37). Periodization was developed with the aim to manipulate training adaptation effects, and avoid the maladaptation phase, which could place the athlete in an over trained state (6,34,39). There is a need for planned variations in the training program to systematically shift the emphasis to promote the different training effects at different phases of the preparation period.

It has been suggested that undulating nonlinear periodized approaches are more viable when planning the training year for team sport (14,39). However, it may be more appropriate to apply a classical approach to periodization during the off-season and pre-season phases. Some authors suggest that the inclusion of lighter percentage repetition maximum (RM) workouts within the training macrocycle is necessary to avoid neural fatigue and potential over training (18,33).

Elite athletes will tend to require more variation to optimize the effectiveness of their training (28,37). During an in-season phase, it has been documented that undulating nonlinear periodization models are typically suggested (39). It has been identified that average training intensity should be maintained above 80% 1 RM to maintain strength levels during playing season (20). High loads >80% 1RM, or >8RM are implemented 2 days per week for multijointed lifts. This loading scheme is shown to maintain or even increase strength levels throughout the playing season in American Football (20).

By definition, periodization concerns variation of training. It seems unlikely that a single optimal periodization training scheme exists that will elicit superior improvements when applied for extended period of times. It is also apparent that a range of periodization strategies implemented in combination will produce the best results through a long-term training cycle (28).

(Turner 2011)

The purpose of this article is to review all pertinent literature reviewing the theories and common practices of periodization in team sports. A common theme throughout all the periodization protocols is the need to manipulate volume loads, progress from general to sport-specific training, and dissipate fatigue.

Periodization may be defined as a training plan; whereby peak performance is brought about through the potentiation of biomotors and the management of fatigue and accommodation. This is principally achieved through the logical yet creative variation of training methods and volume loads (50). Pisk and stone (64) suggest that periodization is applied on a cyclic or periodic basis and is structed into macro-, meso-, and microcycles with progress from extensive to intensive workloads. During the competitive phase; Nadori and Granek (59) suggest that as a minimum objective, the work capacity developed during the SSPT should be maintained. It should be noted that a large portion of evidence to support periodized strategies are based on the hypothesis-gathering studies, anecdotal evidence, and related research (8,16,21,64,72)

It has been established that to adapt to the training process, a proper amount of recovery must be allotted (26,27). According to Stone et al. (74) there is a trade-off between recovery and adaptation that is governed by 3 principle theories: General Adaptation Syndrome (GAS), Stimulus-Fatigue-Recovery Adaptation Theory, and Fitness-Fatigue Paradigm. In addition to application of these three theories, a proper taper period must be applied to allow adaptation. It has been observed by Bosquet et al (6) that a 2-phase taper may be the most beneficial when compared to traditional taper strategies.

Periodization represents an optimal strategy for organizing strength and conditioning programs. The selected strategy should be based on the level of the athlete and the constrains of the competitive season. A common theme throughout all the periodization protocols is the need to manipulate volume loads, progress from general to sport-specific training, and dissipate fatigue.

Section Summary:

The purpose of this section was to conceptualize the theoretical approach to the structuring of in-season practice schedules for American football. Due to the lack of research pertaining to American football, many of the current conclusions are based on studies that have investigated Rugby league play, which is a close match regarding the nature of the sport, and duration of the seasons, as well as the periodized strategies for in-seasons and off season training regimens. In the review done by Peterson et al. (2004), researchers examined the best 'recipe' for maintaining strength gains for in-season, collegiate, professional, and elite athletes. This review (Peterson et al. 2004) indicated that to maintain strength during an in-season period, athletes must train at approximately 85% of 1RM, 2 times a week. In relation to American football practice schedules, this theory is applied to acquiring a game like stimulus at least 2 time per week, with one of those stimuli being a game, to maintain fitness and avoid staleness during competition preparation. In the second study, Baker et al. (2001) demonstrated that strength and power metrics can be maintained, and in some cases increased during a competitive season in rugby league professionals and college-aged individuals. Furthermore, Hulin and Gabbet (2016) elaborated on the acute: chronic ratios indicated that when the acute loads occur to rapidly, not enough, or exceeded the chronic loads players were accustomed to, injury was 16.7% more likely to occur. In addition to these findings, players with a chronically high load were less likely to be injured, illustrating the point that higher chronic training loads may serve as a protective factor against injury. Regarding American football, it is imperative that coaches and sport scientist are mindful of making sure athletes are getting the appropriate stimulus of game like situations per week, not only to maintain fitness but to also protect against injury when game demands may exceed the training stimulus players are accustomed to.

Chapter III

Methods

Experimental Approach to the Problem

To characterize typical volume and intensities for weekday practices, Monday through Friday and competitive games on Saturday, data in the present study were taken from a convenience sample of Division I collegiate football players who wore portable GPS monitors and integrated triaxial accelerometers during the 2016 regular season. All practice sessions and games were recorded over the 13-week regular season, starting in late August and ending in late November. Players participated in five practice sessions with varying planned durations as well as pre-planned practice loads/intensities (Table 1), leading into a competitive game each week. All games were composed of four 15-minute quarters, with a brief intermission between quarters, for a total game duration of approximately three hours and twenty minutes. For inclusion in the study, each subject must have worn a portable GPS monitor for 75% or more of practice and game sessions during the regular season (21). Each athlete was supplied with the same GPS monitor for each data collection period. To capture a representation of player training load for the entire team, each player was chosen as evenly as possible on both offense and defense, matched based on playing position and depth chart status (i.e., offensive linemen counterpart would be a defensive linemen/starters & non-starters). The sample included wide receivers (WR, n=8), quarterbacks (QB, n=1), running backs (RB, n=2), tight ends (TE, n=2), offensive linemen (OL, n=2), defensive linemen (DL, n=2), inside linebackers (ILB, n=2), outside linebackers (OLB, n=2), and defensive backs (DB, n=9). Each player was measured on two GPS variables, total distance – the total amount of distance covered walking, jogging, running, and sprinting and high-speed distance – the amount of distance covered at a velocity greater than 75% and individuals maximum speed at any point.

Table 1. Weekly periodization strategies during the 2016 regular season and the observed training goals. Descriptions of duration, volume/intensity, and the training goal are explained.

Day of the Week	*Duration (mins)*	*Volume/Intensity*	*Training Goal*	*Achieved Training Goal*
Monday	70 minutes	Moderate volume/Moderate Intensity	Training Volume – 75% Training Intensity – 75%	50% of game load (both Volume/Intensity)
Tuesday	110 minutes	High volume/High Intensity	Training Volume - ≥ 85% Training Intensity -≥ 85%	Training Volume – 87% Training Intensity – 55%
Wednesday	110 minutes	High volume/high intensity	Training Volume - ≥ 85% Training Intensity -≥ 85%	Training Volume – 85% Training Intensity – 35%
Thursday	45 minutes	Low volume/low intensity	Training Volume – 50% Training Intensity – 50%	Training Volume – 50% Training Intensity – 100%
Friday	55 minutes	Low volume/High Intensity	Training Volume - 60% Training Intensity -75-80%	Training Volume – 50% Training Intensity – 28%
Saturday		High volume/high intensity	Training Volume - 100% Training Intensity – 100%	Training Volume – 100% Training Intensity -100%
Sunday	OFF	Restorative day	OFF	

Subjects

A convenience sample of thirty Division I National Collegiate Athletic Association (NCAA) football players from the Southeastern Conference (SEC) participated in the present study. The mean ± SD height and weight for each positional group are shown in Table 2. From this sample, there were 18 starters and 12 non-starters. All participants were on the team one year prior to the current study (2016 season), and was familiarized with the technology being worn. The GPS data was de-identified and presented to researchers for the 13-week regular season. Ethical approval was be obtained from the University of Kentucky's Institutional Review Board and all subjects signed an informed consent form.

Table 2. Positional groupings of height and weight expressed as means ± SD.

Position	*Number of subjects*	*Height (in)*	*Weight (kg)*
DB	9	185.2 ± 10.1	88.3 ± 5.1
DL	2	182.8 ± 6.3	131.8 ± 2.5
ILB	2	187.9 ± 8.9	105.0 ± 7.1
OLB	2	191.8 ± 7.4	110.2 ± 8.1
WR	8	186.4 ± 11.1	91.4 ± 7.9
TE	2	195.5 ± 5.8	111.4 ± 0.2
RB	2	176.5 ± 6.1	90.0 ± 1.2
QB	1	187.9	83
OL	2	187.8 ± 2.0	140.8 ± 6.4

Procedures

Global Position System Units:

To investigate whether periodization stratiges were met during a 13 – week season in American football, GPS monitors (MinimaxX S5; Catapult Innovations, Melbourne, Australia) was used for the present study. The S5 GPS monitors operated in a non-differential mode at a sampling frequency of 10 Hz and contained an integrated tri-axial accelerometer, which sampled at a rate of 100 Hz and assessed the frequency and magnitude of accelerations ($m \cdot s^{-2}$) in 3 different dimensions (anterior-posterior, mediolateral, and vertical). The validity and reliability of GPS to measure variables such as total distance in a variety of velocity zones and change of direction in both contact and non-contact team sports have been reported (2,5,9,10).

Determination of Volume and Intensity

In this study, the total distance covered was used as a measure of exercise volume. Total distance covered is a GPS variable that is measured through the triangulation of at least four different satellites in communication with the GPS monitor (1). Once in communication, displacement of the GPS monitor was measured in meters (1). In addition, the GPS monitor provides a measure of velocity in units of meters per second (1). The validity and reliability of satellites to measure total distance covered in a variety of speed zones has been well established (1). For the purposes of this study, total distance will be measured in the total amount of yards accumulated by walking, jogging, running, sprinting or even standing and serve as the total exercise volume. To determine the intensity of periodized practice strategies, a variable calculated within the Catapult software package (OpenField, Catapult, Melbourne, Australia), known as high-speed distance will serve as the relative intensity of weekday practices and competitive games. High-speed distance was defined as the total yardage covered at a velocity that is 75 percent or greater of the athletes' maximal velocity achieved at any point during practice or games.

This study also examined the relative contribution of the variables total distance (volume) and high-speed distance (intensity) to the prediction of player load. The Player Load variable is a modified vector magnitude developed and calculated by Catapult Innovations using the MinimaxX accelerometer data. Player Load is defined as the square root of the sum of the squared instantaneous rate of change in acceleration in each of the three vector planes (anterior-posterior, mediolateral, and vertical) divided by 100, which can be seen in the following equation:

$$Player\ Load = \sqrt{\frac{(a_{y1} - a_{y-1})^2 + (a_{x1} - a_{x-1})^2 + (a_{z1} - a_{z-1})^2}{100}}$$

Where a_y is equal to anterior-posterior acceleration, a_x is equal to mediolateral accelerations, and a_z is equal to vertical accelerations. Player load is a variable that is expressed in arbitrary units (AU). Player load has been shown to be related to total distance, change of direction, and explosive movements during field based sports (9,10). Player load is calculated from any ground reaction force that causes anterior-posterior, mediolateral, or vertical accelerations. These accelerations are entered into a proprietary player load formula, which has been described as a reflection of the physical demands of any field based movement (12). Although player load has been reliably measured in field-based sports (9,10), due to the proprietary nature of the formula used to calculate player load, this variable cannot be validated.

Periodized Practice Strategies

To examine if periodized strategies are met during a week of practice leading into a competitive football game, GPS monitors will be used to determine the volume (total distance) and intensity (High Speed Distance >75%) achieved. The strength and conditioning staff was responsible for the structure of the periodized practice plan, which followed basic in-season periodization techniques designed to incorporate the theories of GAS, SFRA, and Fit-Fat. The periodized model can be seen in Table 1.

Statistical Analyses

To determine periodized strategies in preparation for game play, each weekday practice was averaged over the 13-week season as well as each competitive game. Separate one-way repeated measures ANOVAs were used to determine if there were differences among weekday training sessions versus Saturday games for total distance and high-speed distance ≥75%. In addition, stepwise linear regression was used to examine the relationships among the predictor variables (total distance and high-speed distance) and player load, as indication to which variable best-predicts player load. An alpha level of $P \leq 0.05$ was used for all ANOVA analyses. Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS for Windows, version 24.0; SPSS, Inc., Chicago, IL, USA).

Chapter IV

Results

Weekday and Game day comparisons for exercise volume (total distance) and intensity (high-speed distance)

The Mean ± SD of weekday and game day total distances (yards) are shown in Table 3. Figure 1 displays the average total distances and high-speed distances covered for the weekday practices and competitive games. The one-way repeated measures ANOVA indicated differences in the total distances covered among weekday practices and competitive games ($F = 1051.99$, $P < .01$). The follow up pairwise comparisons (Table 3) indicated competitive games on Saturday resulted in the greatest total distance (4316.8 ± 1101.2 yd) compared to all weekday practices. The total distance for Tuesday's practice (3730.2 ± 719.5 yd) was greater than all other weekdays. Wednesday (3397.8 ± 687.3 yd) resulted in greater yards than Monday (2024.1 ± 428.6 yd), Thursday (2049.8 ± 637.3 yd), and Friday (2252.4 ± 430.3 yd). The total distance for Thursday was not significantly different from Monday or Friday, but Monday's total distance was less than Friday's total distance. The amount of total distance covered on Thursday was less than the distance covered on Tuesday, Wednesday, and Saturday.

The Mean ± SD of weekday and game day high-speed distances (≥ 75% max. speed) are shown in Table 4. The one-way repeated measures ANOVA indicated differences in the amount of high-speed distance covered among weekday practices versus competitive games ($F = 61.9$, $P < .01$). The post-hoc pairwise comparisons (Table 4) indicated that competitive games on Saturday resulted in the greatest amount of high-speed distance covered (120.9 ± 95.8 yards) compared to all other weekday practices. The high-speed distance covered during Tuesday's practices (65.5 ± 58.1 yd) was greater than all other weekday practices expect, Wednesday (53.3

± 51.8 yd). There was also not a statically significant difference in the amount of high-speed distance covered between Wednesday's practices and Friday Practices (33.2 ± 32.8 yd). Thursday Practice (0.0 ± 0.0) had the lowest amount of High-speed distance covered over the course of the week.

The stepwise linear regression analysis indicated that total distance significantly predicted player load, whereas high-speed distance did not (Player load = 0.09 [Total Distance] + 18.96; [r^2 = 0.91; SEE = 31.4 yd; P < 0.001]).

Table 3: Mean ± SD of weekday and competitive games for total distance. Competitive games were played on Saturday.

Day of The Week	*Total Distance (Yards)*		
Monday	2024.1	±	428.6 [2,3,5,6]
Tuesday	3730.2	±	719.5 [1,3,4,5,6]
Wednesday	3397.8	±	687.3 [1,2,4,5,6]
Thursday	2049.8	±	430.3 [2,3,6]
Friday	2252.4	±	430.3 [1,2,3,6]
Saturday	4316.8	±	1101.2 [1,2,3,4,5]

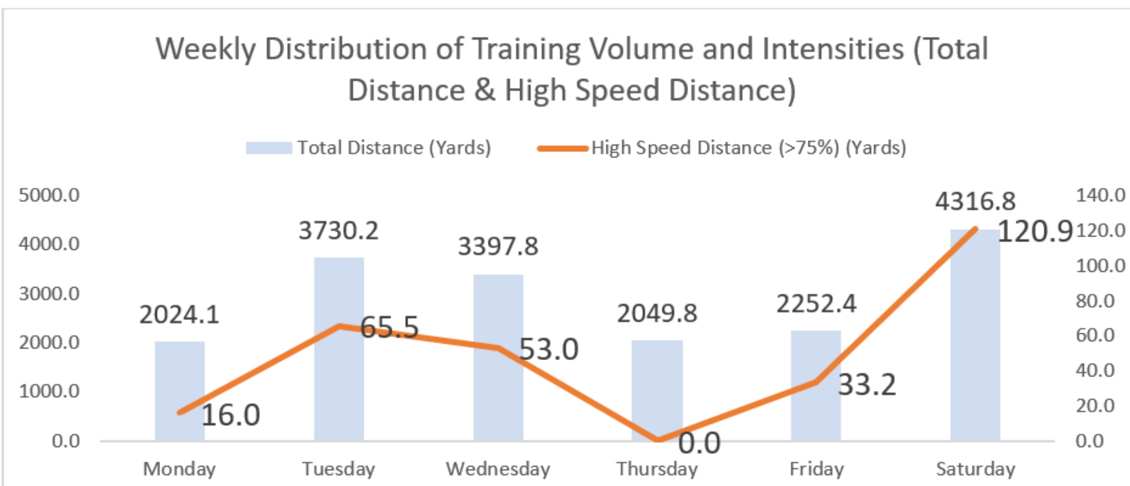
Superscripted numbers indicate a statistically different amount of total distance covered when compared to that day (p -value <0.05). 1 = Monday, 2 = Tuesday, 3 = Wednesday, 4 = Thursday, 5 = Friday, 6 = Saturday.

Table 4: Mean ± SD of weekday and competitive games for High-Speed Distance ≥75%. Competitive games were played on Saturday.

Day of The Week	*Total Distance (Yards)*		
Monday	16.0	±	13.5 [2,3,4,5,6]
Tuesday	65.5	±	58.2 [1,4,5,6]
Wednesday	53.0	±	51.8 [1,4,6]
Thursday	0.0	±	0.0 [1,2,3,5,6]
Friday	33.2	±	32.9 [1,2,4,6]
Saturday	120.9	±	95.8[1,2,3,4,5,6]

Subscripted numbers indicate a statistically different amount of High-speed distance covered when compared to that day (p -value <0.05). 1 = Monday, 2 = Tuesday, 3 = Wednesday, 4 = Thursday, 5 = Friday, 6 = Saturday

Figure 1: Weekly distribution of load and intensities for division I football players. Shown is the average of each weekday as well as competitive games over the 13-week season.



Chapter V

Discussion

One of the primary purposes of this study was to characterize the typical volume and intensity of weekday practices and competitive games and compare practice volumes and intensities to competitive games to describe a periodized training model. Utilizing GPS technologies, the amount of total distance (yards) accumulated was defined as the total volume produced by the athlete, whereas the amount of high speed distance (≥ 75% of max speed) accumulated was defined as the relative intensity performed by the athlete. It was hypothesized that competitive games played on Saturday would demonstrate the highest amounts of volume and intensity, and that subsequent training days were designed during the week to combat the higher volume and intensities of competitive game play on Saturday, as implied via the training theories of General Adaptation Syndrome (GAS), Stimulus-Fatigue-Recovery Adaptation Theory (SFRA), and Fitness-Fatigue Paradigm (Fit-Fat)(3,8,15,20). Specifically, because of the higher loads and intensities of games, the training program was designed so that weekday practices loads oscillated throughout the preparatory week to aid in the recovery, leading to the implementation of GAS. The goal was for Tuesday and Wednesday practice sessions to be of the highest loads of the week and thus should be within 85% or more of a game load (20). This was planned due to the theory of SFRA and residual training effects (20). In addition, the strength and conditioning staff sought to design a program to maintain athlete top end speed (i.e., maximum speed) throughout the season. According to Issurin and Lusitig (20), the residual training effects of maximum speed are 5±3 days. Thus, following a competitive game on Saturday, this training window fell within the training days of Tuesday and/or Wednesday, which also allowed sufficient time for recovery before the next competitive game on Saturday. Thus, the goal established by the strength and conditioning staff was for the athletes to cover, on average, 3,600 yd of total distance and 100 yards of high speed distance for these practice sessions on Tuesday or Wednesday. Leading into a competitive game, the strength and conditioning staff also implemented a 2-phase taper model following the theory of Fit-Fat. The 2-phase taper was applied on Thursday, Friday, and Monday sessions. Following a high stimulus day on Wednesday, the staff intended to decrease overall volume and intensity by 50% or more for Thursday's practice session, as this session was devoted as a walk-through session. To follow a 2-phase taper model, a moderate increase in total distance to no greater than 80% and no less than 70% of game demands was implemented to cause upregulation of the CNS prior to a competitive game (2). With this 80% increase during Friday practice sessions, athletes were expected to accumulate no more than 3,400 and no less than 3,000 yards of total distance and to achieve no more than 90 yards and no less than 75 yards of high speed distance prior to a competitive game. The same approach was utilized on Monday training sessions following a day of recovery on Sunday.

Based on the current findings, the overall training model proposed by the strength and conditioning staff was not supported, due to lower volume and intensities achieved than sought during weekday practices. The results of the current study indicated that as a team, there was a significantly greater amount of high-speed distance (120 ± 95.8 yd) and total distance (4316.8 ± 1102.1 yd) covered during Saturday games compared to all weekday practices. These findings supported the first assumption of the proposed model that throughout the week competitive games played on Saturday would be of the highest loads and intensities. The results also indicated that Tuesday's practice sessions included the highest amount of total distance (3730.2±719.5 yd) and high-speed distance (65.5±58.2 yd) covered during the week and was also statistically lower than those loads achieved on competitive games. The total distance was slightly greater than the goal distance of 3600 yards and the high-speed distance was slightly less than the goal of 100 yards. This total distance was within 87% of total distance of the games and indicated that in terms of load, this was an adequate stimulus based on the theories of GAS and SFRA. However, team average high-speed distance was within 55% of high-speed distance of games and indicated that the overall goal achieving a high intensity practice was not achieved. Due to NCAA rules and regulations about the amount of time student-athletes are required to be held within their respective sports, it was very unlikely that every player would achieve a high stimulus in one training session (i.e. Tuesday). For that reason, it was sought out that Tuesday's would represent mostly key contributors, while Wednesday session would be a second opportunity for reserve players to achieve a higher stimulus. This was also detected within GPS technologies with the amount of total distance (3397.8 ± 687.3 yd) and high-speed distance53.0 ± 51.8 yd) significantly greater than all other weekday practices, except for Tuesday and Saturday sessions. Likewise, the overall volume of the session was within the training goal of 85% of game loads, but overall high-speed distance (53 yards) was roughly 35% lower than game intensities, thus not supporting the goals of the prescribed training model. Lastly, the team demonstrated a large decrease in volume and intensity during Thursday practices (2049.8±430.3; 0.0±0.0), followed by a moderate increase in the amount of high-speed distance (33.2±32.9) while keeping overall volume low (2252.4±430.3) on Friday practices. This design was utilized to prevent staleness and create up-regulation of the central nervous system prior to competitive games on Saturday (3). Thursday practices showed a 50% decrease in the overall training load for the practice, and a 100% decrease in the overall intensity. This very large decrease in training intensity likely occurred due to the nature of this practice, as it was designed to be a walk through in which players were instructed to visualize and walk through their plays. However, Friday's were designed to stimulate the athletes through higher amounts of high-speed distances and is not statistically different from Wednesday practices, which were designed to be of higher stimuli. Although this increase from Thursday to Friday's was a low to moderate increase, it still was not high enough based on the goal of the model, as the amount of high-speed distance should have been 80% of a game load. Following a competitive game, Sunday served as the teams' mandatory day off per NCAA rules and regulations. Because of that reason, Sunday served as a second classical reduction in volume and intensity, causing Monday practice sessions to have moderate levels of load and intensities (2024.1 ± 428.6; 16.0 ± 13.5 yd respectively) before the reintroduction of a higher stimulus brought on because of the theories of residual training effects. Again, it was observed that the overall team training load was appropriate, but the overall training intensity was too low (less than 70-80%). It was the goal of the proposed model that these three days served as proper tapering days and can be seen by not being statically different from each other regarding total exercise volume and being statistically different between other weekday practices and competitive games.

A secondary purpose of the present study was to examine the relationship among total distances and high-speed distance in the prediction of player load. The current findings indicated total distance was responsible for 91% of the explained variance in the prediction of player load. This study, however, was limited to the inclusion of only two variables in the prediction of player load due to small sample size. Future studies should examine the prediction of player load with the inclusion of more variables captured through the GPS technologies (e.g., player load per min, total IMA, acceleration, deceleration, change of direction left/right, contact forces, and body mass) as well as within each position group.

Although the present study demonstrated the application of a complex in-season periodized model, there are some limitations to this approach that are noteworthy for future applications. In the present study, the amount of high-speed distance performed during each of the days is relatively low (i.e., Monday training days = 16 yd). This may be due to a couple of factors. First, the data were analyzed from a team perspective. Typically, skilled positions such as wide receivers, defensive backs, and running backs will accumulate much more high-speed distances than bigger athletes such as linemen due to the nature of the game and the lack of sprinting involved with that position group. By incorporating linemen and skilled athletes into one group of data instead of separately, the lower achieving high-speed distances will bring the overall averages down. It is for that reason future studies should analyze the description of American football based on playing position. Secondly, the amount of high-speed distance based off 75% of and individual players max velocity is independent of playing position and may lead to over estimation in the amount of high-speed distance in linemen and under-estimate the amount of high-speed distance in skilled athletes (18). In the present study, these thresholds were set by the manufacturer and instead the percentages of max speed should be set by the individuals max speed based of a positional norm (18). However, due to limited sample sizes per positional group these analyses were not possible. Thus, future research should include position specific running demands to determine the amount of high-speed distance being achieved. Thus, although high-speed distance did not significantly contribute to the prediction of player load when the team was examined as a whole, it may have more relative importance within positional groups, such as receivers and running backs. Future studies should examine the contribution of high-speed distance to the player-load prediction in positional groups. Lastly future studies should identify other potential metrics to track of training volume and intensities. Although total distance and high-speed distance are valid metrics via GPS, it may be of more benefit (based on the sport being played) to identify parameters that capture more of the tempo of play rather than over-all intensity. In addition to this, it may be that during practice sessions, the practice plays/scripts may not allow an athlete to accumulate large amounts of high-speed distance due to either plays being called, rotations with other players, or field limitations which is why a tempo may be useful in identifying training intensity.

The results of the present study indicated that total distance, but not high-speed distance, could best be used to describe and track the development of a periodization model for training in Division I American Collegiate Football using GPS technologies. Future studies should include larger sample sizes as well as the number of GPS variables included in the analysis such as different speed zones, change of direction, accelerations, and decelerations to better describe the game being played. In addition to larger sample sizes and variables, other studies should test if a particular periodized strategy works through the use of performance outcomes such as cortisol/testosterone concentrations or neuromuscular testing, in conjunction with a regular in-season strength and conditioning training program. To practically apply the use of GPS technologies into team sports, it is imperative to first describe the sport that is being played. Practitioners should be aware of the demands of each playing position, so that in training, these positions are meeting the demands of the game. Once these playing demands are established, the use of proper load monitoring through GPS may be useful, to aid in the prediction/prevention of soft tissue injuries.

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