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# QUANTIFICATION OF IN-PLAY COMPETITION DEMANDS OF COLLEGIATE AMERICAN FOOTBALL PLAYERS USING GLOBAL POSITIONING SYSTEMS

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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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Lexington, Kentucky

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2021

ABSTRACT OF THESIS

QUANTIFICATION OF IN-PLAY COMPETITION DEMANDS OF COLLEGIATE AMERICAN FOOTBALL PLAYERS USING GLOBAL POSITIONING SYSTEMS

There is limited information describing the competition demands of American football. A greater understanding of competition demands will allow strength and conditioning practitioners to create appropriate training programs to enhance athlete readiness and performance. Therefore, the purpose of this study was to analyze the competition demands of collegiate American football players using global positioning systems (GPS), specifically comparing the in-play GPS versus out-of-play GPS outcomes. Twenty-two American football athletes (Age: 20.8 ± 0.9 yr, Height: 190.2 ± 4.7 cm, Body mass: 113.4 ± 22.3 kg) were monitored during 12 regular season competitions over 13 weeks. Athletes were divided into specific offensive and defensive position groups. The study utilized relative velocity zones to determine the distance traveled by athletes in different velocity zones. In-play GPS variables were stratified from out-of-play GPS variables using velocity tracings from Openfield software and competition video. Paired samples T-tests were used to identify differences between in-play and out-of-play variables. The findings indicate that total duration, total distance, standing distance, walking distance, and jogging distance were significantly lesser for in-play versus out-of-play ($p<0.001$), and extensive tempo distance, intensive tempo distance, sprint distance, and intensity were significantly greater for in-play versus out-of-play ($p<0.001$). The results of the present study provides novel insights regarding the in-play competition demands of collegiate American football and provides a different method of analyzing American football.

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Date

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TABLE OF CONTENTS

LIST OF TABLES

# CHAPTER 1: INTRODUCTION

American football is a field sport composed of brief intermittent, high-intensity work bouts followed by longer periods of recovery [1]. American football utilizes multiple biomotor abilities including, muscular strength, muscular power, speed, agility, and mobility [2]. During a season, National Collegiate Athletic Association (NCAA) Division I college football programs in the Football Bowl Subdivision (FBS) compete in 12 regular-season games over a 13-week period. Research evaluating the physical game demands of American football is extremely limited [1, 3-6]. The initial research involving the game demands of American football used time-motion analysis to identify work-to-rest ratios, series per game, and plays per series, while specifying the differences in duration of run and pass plays [1, 3]. Rhea et al. [3] found that the average NCAA football game was composed of $13.8 \pm 2.2$ series per game and $6.3 \pm 3.3$ plays per series with an average work-to-rest ratio of 5.6:34.0 (s). Although informative, these descriptive statistics do not provide adequate information to contextualize the physical demands of American football. Strategically, the game is divided into offensive and defensive units, within which there are multiple positions groups that have varied tactical responsibilities and distinct physical demands [7].

Research surrounding the demands of American football was taken a step further when wearable technology, including global positioning system (GPS), accelerometry, and heartrate monitoring, were used to describe the position-specific demands of American football [4-6]. Specifically, Wellman and colleagues [4] noted significant differences in the total distance, low intensity distance, moderate intensity distance, sprinting distance, and average maximal speed in running backs, quarterbacks, tight ends, and offensive linemen versus wide receivers during competition. It was also noted that there were significant differences in total distance, low intensity distance, moderate intensity distance, sprinting distance, and average maximal speed in defensive tackles, defensive ends, and linebackers versus defensive backs. The research conducted by Wellman et al. [4] and Bayliff et al. [5] has provided context to the existing time-motion analysis research of American football [1, 3]. Combining the position-specific movement demands and time-motion analysis data to determine the in-play movement demands of American football provides a novel understanding that performance specialists can use to increase the degree of training specificity in an effort to optimize athletic performance.

Substantial improvements in wearable GPS technology enabled performance specialists to understand the movement characteristics of field sports [8]. Performance specialists have used wearable GPS to measure maximal running velocity, total distance, and distance covered in different velocity zones [4-6, 8-15]. The use of GPS to evaluate competition demands in team sports has been previously deemed valid and reliable [16-19]. In addition, the quantification of competition demands using GPS has been determined in other field sports, such as rugby [9-11], Australian rules football [13, 14], and soccer [12, 15]. Other field sports differ from American football due to their continuous activity. The GPS research used to determine competition demands in rugby [9, 10] and soccer [12, 15] was continuously recorded from the onset of play until the conclusion of competition. However, if an athlete was not actively participating in the competition, the GPS data were excluded from the studies. American football's starting, stopping, and substitution styles make it increasingly challenging to exclude data when players are not actively participating. Therefore, analyzing American football in the same continuous manner as other field sports may not provide a true representation of the competition demands required for American football athletes. Bayliff and coworkers [5] attempted to address this issue by removing the unwanted "noise" that included time-outs and time between quarters and halves. However, this approach does not eliminate the time between series or plays when athletes are not actively competing, thus likely biasing the velocity and distance metrics due to lower intensity out-of-play activity. Therefore, the purpose of the present study was to accurately describe the competition demands of NCAA Division I FBS American football players using wearable GPS technology and to compare the in-play versus out-of-play GPS demands. We hypothesized there would be greater in-play distance at high velocities versus out-of-play distance at high velocities, lesser in-play total distance versus out-of-play total distance, and higher in-play intensity versus out-of-play intensity. The insights obtained from this study will provide performance specialists with a means to improve the specificity of training programs for American football to enhance performance outcomes.

# CHAPTER 2: LITERATURE REVIEW

## 2.1 AMERICAN FOOTBALL BACKGROUND

The body of literature surrounding American football since its conception in the late 19th century is somewhat limited. The methods used to analyze American football have evolved since the earliest research publications. Most of the initial research provides the background of American football. Advancements in technology, the efficacy of that technology, and the information it provides researchers has increased the understanding of American football. GPS technology has been particularly useful to understand the game demands of the sport.

American football is unique in that the sport is relatively new in relation to other team sports, and it is primarily practiced in one central geographic location. It was reported that the National Football League (NFL) brought in over $8 billion in revenue in 2010 [20]. The lucrative business model of American Football has influenced the degree to which the sport is analyzed. Player performance, and the key performance indicators that promote successful play, have been at the forefront of research. The volume of research surrounding American football is somewhat limited compared to other field sports such as rugby and soccer due to its comparatively young age and lack of international participation.

Early literature surrounding American football was extremely primitive due to a lack of preexisting information and minimal technology. The initial literature primarily consisted of books providing the game's rules and guidelines for athletes to be successful at the sport [21, 22]. Some of the early key performance indicators identified for certain positions include fast and powerful linemen, along with fast players in the backfield [21].

American football's earliest athletes were instructed to get adequate sleep, maintain hydration levels, and consume sufficient amounts of food to improve on-field performance and prevent overtraining [22]. During the late 19th and early 20th centuries, not long after the sport with first recognized, the literature highlighted key performance indicators and strategies that enhanced on-field performance.

Starting in the 1930's researchers began to analyze the relationship between reaction time and on-field performance. During this time period, the positions with the fastest athletes and the quickest reaction time played guard, tackle, and on the ends of the line of scrimmage [23]. This is the opposite of what is seen in present-day American football, where skilled positions are noted as being the fastest players on the field [4, 5]. Initial research involving charging reaction time (i.e., the time it takes athletes to react to the ball being snapped) was used to analyze how well coaches evaluated athletes for performance characteristics at Stanford University [23]. Eventually, the research developed into investigating the relationship between hand and foot reaction time with objective measurements of a high school athlete's ability to play American football [24]. In both instances, reaction time was being investigated as a key performance indicator that promoted success in American football.

American football athletes' body size and composition was another area of focus in early football research [25-27]. Body composition and size differences among positions were initially reported and traditionally used as reference values for other research by Wilmore and Haskell in 1974 [7, 26]. American football athletes at 13 different universities in the same year were compared to athletes at the same universities ten years later in 1984 [27]. The results showed increases in size, strength, and speed at almost every position [27]. Over time, athletes have generally continued to increase in size, strength, or speed metrics at nearly every position [7, 25]. Thus, further expressing how key performance indicators such as size, strength, speed, or a combination of the three were the focus of the majority of American football literature in the beginning.

As the volume of American Football research increased over time, the focus shifted from identifying key performance indicators to identifying the demands of the game. However, both are crucial to the development of athletes in team sport. Understanding the demands of the game allows researchers to conduct a needs analysis to accurately identify the key performance indicators that enable athletes to perform the demands placed upon them to the highest degree. Without knowing the demands of the game, researchers can only associate an athlete's physical and performance characteristics with performance outcomes in the sport.

Early references to the physiological demands of American football largely came from the Soviet Union [2, 28]. Initial publications provided physiological characteristics to consider when creating a strength and conditioning program for American football athletes [28]. Verkhoshaski stated that American football athletes were required to possess quick acceleration and deceleration abilities, high running velocities, superior jumping ability, the ability to produce force explosively, speed endurance, strength endurance, and protective strength [28]. He expands on the list of key performance indicators by explaining how to train for the physiological adaptations needed to produce the described qualities. The bulk of his recommendations surrounded the need for optimal function of the human system to produce a high enough aerobic capacity for work and recovery and maximal anaerobic power for powerful movements and acceleration [28].

A review conducted by Pincivero & Bompa described the physiological demands of American football while highlighting energy system utilization during competition [2]. It has been speculated that the phosphagen and glycolytic energy systems provide the majority of energy production for American football athletes, with the phosphagen energy system providing approximately 90% and the glycolytic energy system providing the other 10 % of energy production [29]. American football athletes have been observed to have high concentrations of fast-twitch muscle fibers with depleted muscle glycogen stores and a 3- to 5- fold increase in blood lactate concentration post-competition [30]. The evidence provided supports the notion that energy production for American football athletes is primarily supplied by the phosphagen and glycolytic energy systems [2].

The physiological demands of American football had widely been speculated without a specific understanding of the competition modeling. However, time-motion analysis research provides insight into the exercise to rest ratios during American football competitions [1, 3]. Initial research conducted by Rhea et al. [3] identified the competition work-to-rest ratios, length of series, plays per series, and specified differences in play duration for run and pass plays at the high school, college, and NFL levels of American football. The study timed the play duration from the moment the ball was snapped until the referee blew the whistle at the conclusion of the play. In addition, the recovery duration between plays was timed from the moment the referee blew the whistle at the conclusion of a play until the onset of the next snap of the football. It was determined that the average work-to-rest ratio of collegiate football competitions was 5.6:34.0 (s). The information provided by Rhea et al. [3] can be utilized to increase the specificity of American football training programs and further the understanding of energy system utilization and the bioenergetic demands of the game.

## 2.2 GLOBAL POSITIONING SYSTEMS

Advancements in technology eventually led to the development of wearable devices that could be used to measure athletic performance. The wearable technology developed has been used to analyze the demands of American football. Specifically, global positioning systems (GPS) have been used to quantify the physical demands of the game [4-6]. Wearable GPS technology has been used in a variety of other field sports as well. Similar to American football, the technology was used to quantify the physical demands of rugby, soccer, and Australian rules football [9-15].

The use of GPS to quantify the physical game demands has previously been deemed valid and reliable [8, 16-19]. The most popular technique for determining the validity of a GPS has been to select a known distance and use timing gates to measure the time it takes to travel the distance. The time it takes for the GPS device to travel the known distance is then compared to the data recorded by the GPS device [8]. It has been noted that there are limitations to using GPS devices with a sampling frequency of 5 Hz when analyzing high-intensity running, velocity measurements, and short linear running [16]. However, these limitations are diminished when using GPS devices with a 10 Hz sampling frequency [16]. Ironically, the same increase in validity is not observed between GPS devices with 10 versus 15 Hz sampling frequencies. In fact, GPS devices with a sampling frequency of 10 Hz have been proven to be superior to GPS devices with a sampling frequency of 15 Hz in the existing literature [18]. Similarly, the reliability of the GPS devices improves with increased sampling frequencies [16]. The intraunit reliability was demonstrated to be higher than the interunit reliability on almost all occasions, and it was noted that athletes should use the same device to decrease error when tracking over multiple sessions.[16]

The first use of GPS to quantify the demands of the game in American football analyzed 49 National Collegiate Athletic Association (NCAA) Division I Football players during preseason training [6]. The purpose of the study was to compare the distances traveled by lineman versus non-lineman and starters versus non-starters during specific practice drills in preseason training in the heat [6]. DeMartini et al. [6] determined that non-lineman traveled significantly farther than linemen during team drills and the entire practice. Also, it was shown that starters covered more distance than non-starters during team drills but not during practice as a whole [6]. This study provided coaches with an understanding of the GPS demands of specific demographics of an American football team during preseason training in the heat. However, the information provided could only be used to provide insights to coaches on that specific team. Due to differences in practice schedules, practice structures, and drill types used during practice at other institutions, it is difficult to make accurate comparisons to American football athletes competing at other Division I programs.

GPS data recorded during competition were needed to effectively compare the GPS demands of American football from one program to another because of the standardization that comes with it. During an American football competition, all teams have the same objective, score more points than the opponent. There is also a standard game duration. There are different strategies that can be used to complete the objectives, but all are centered around the offense running and passing the football and the defense stopping the other team from doing the same.

Eventually, researchers [4, 5] determined the GPS demands of a standard competition that could be applied to other Division I American football programs. The research by Wellman et al. [4] compared the competition demands of 33 Division I American football athletes over a 12 game season. The average competition demands of each position group were determined via commercially available GPS receivers (SPI HPU; GPSports, Canberra, Australia) that recorded data from the onset of the first play until the conclusion of the final play during each competition [4]. Participants in the research conducted by Wellman et al. were required to participate in a minimum of 75% of the total offensive or defensive plays to be included in the study [4]. Absolute velocity zones were defined to determine the distance traveled by athletes at low-intensity (0-10 km/h), moderate-intensity (10.1-16 km/h), high-intensity (16.1-23 km/h), and sprinting (>23.0 km/h) distances [4]. There are inherent disadvantages to using absolute velocity zones due to differences in maximal running velocities between position groups [4, 5]. Using absolute velocity zones can lead to the under-reporting of distances traveled in higher velocity zones for position groups with lower maximal velocity. Wellman et al. determined that there were differences in total distance (m), low intensity distance (m), moderate intensity distance (m), high intensity distance (m), and sprinting distance (m) for wide receivers (WR) versus running backs (RB), quarterbacks (QB), tight ends (TE), and offensive linemen (OL) [4]. Differences were also observed for defensive backs (DB) versus defensive tackles (DT), defensive ends (DE), and linebackers (LB) [4].

Bayliff et al. [5] conducted a study that was extremely similar to previous research that quantified American football's competition demands using GPS with a slight difference in methodology. Data recorded by GPS devices during time-outs, between quarters, and during halftime were excluded from the study and defined as unwanted "noise" [5]. Similarly, participants in the research conducted by Bayliff et al. were required to participate in a minimum of 2/3 of offensive or defensive plays in the nine in-conference games to be included in the study[5]. The slight alteration in methodology found that the total distance traveled by DB's versus WR's and OL, but no difference in DB's versus Defensive Linemen (DL) [5].

The methodologies used by Bayliff et al. [5] were similar to methods seen in the GPS research of other team sport. Research conducted in soccer and rugby excludes data for athletes when they are not actively participating in competition [9, 10, 12, 15]. The method of benching athletes enhances the analysis of competition demands because it filters out the "noise" described by Bayliff et al. [5]. However, the starting, stopping, and substitution style of American football make it extremely difficult to filter out all of the unwanted "noise." The continuous nature of sports like rugby and soccer makes benching players much easier because of the lack of substitutions that occur throughout a competition compared to American football. The thought of initially benching players during downtimes by Bayliff et al. [5] is a step in the right direction for American football, but it still does not account for times when the opposite side of the ball is on the field and time between plays.

The initial American football research is extremely limited because of the sports relatively young age, primitive technology, and lack of global adoption[21-24, 27]. As the popularity of American football increased, so did the body literature that analyzed the relationship between key performance indicators and on-field performance. Enhancements in technology enabled researchers to develop new methods for determining the demands of American football. One of the methods used was GPS. The validity and reliability of GPS to measure the demands of team sports has been demonstrated in the literature [8, 16-19]. The methods used to measure game demands via GPS in other team sports differ from the methods used in American football, and new methods and analyses are needed to more accurately quantify the demands of American football competition[4, 5, 9, 10, 12, 15].

# CHAPTER 3: METHODS

## 3.1 EXPERIMENTAL APPROACH TO THE PROBLEM

This study utilized a descriptive within subjects comparison of in-play versus out-of-play competition demands in collegiate American football players using portable GPS technology. The GPS data were collected over 13 weeks during 12 NCAA Division I FBS football games. The independent variable in this study is in-play versus out-of-play classification, whereas the dependent variables included total duration, total distance, distances traveled at different velocities, and ambulatory intensity.

## 3.2 SUBJECTS

Twenty-two NCAA Division I FBS football players (Age 20.8 ± 0.9 yr, Height 190.2 ± 4.7 cm, Body mass 113.4 ± 22.3 kg) were recruited to participate in the study. The height and body mass for each position group are presented in Table 1. To be included in the study, participants were required to participate in a minimum number of plays equal to or greater than the average total plays participated in by all players in their respective position groups. A breakdown of athlete participation is shown in Table 2. Due to injury and GPS device malfunction, six participants are missing data from one game. For instances where the GPS devices malfunctioned, the play total from that game was still attributed to the total number of plays that the athletes participated in during the season. All participants participated in an 8-week summer strength and conditioning training protocol and four weeks of football-specific training prior to initiation of the study. Each participant was outfitted with custom equipment (i.e., shoulder pads and helmets) by the university equipment staff prior to the start of football-specific training.

Ethical approval was obtained from the University's Institutional Review Board (Protocol #45355), and all participants provided written informed consent prior to participation in the study.

Table 3.1 Physical characteristics of participants by position group.

| Position (N=22) | Height (cm) | | | Weight (kg) | | |
|---|---|---|---|---|---|---|
| DB (n=4) | 186.7 | ± | 4.4 | 91.4 | ± | 4.4 |
| DL (n=4) | 193.0 | ± | 2.0 | 137.4 | ± | 14 |
| ILB (n=2) | 186.7 | ± | 1.8 | 104.6 | ± | 7.7 |
| OL (n=4) | 193.0 | ± | 4.6 | 141.3 | ± | 3.7 |
| OLB (n=2) | 193.0 | ± | 3.6 | 112.3 | ± | 8.4 |
| QB (n=1) | 190.5 | ± | 0.0 | 93.2 | ± | 0.0 |
| RB (n=1) | 180.3 | ± | 0.0 | 101.4 | ± | 0.0 |
| TE (n=1) | 195.6 | ± | 0.0 | 114.6 | ± | 0.0 |
| WR (n=3) | 188.8 | ± | 2.3 | 90.9 | ± | 2.3 |

DB: Defensive back; DL: Defensive linemen; ILB: Inside linebacker; OL: Offensive linemen; OLB: Outside linebacker; QB: Quarterback; RB: Running back; TE: Tight end; WR: Wide receiver

Table 3.2 Frequency of play participation by position throughout a football season.

| Athlete | Position | Plays participated in (#) | Plays not participated in (#) | Relative play participation (# of plays participated in / total plays) |
|---|---|---|---|---|
| 1 | DB | 629 | 122 | 0.84 |
| 2 | DB | 653 | 98 | 0.87 |
| 3 | DB | 578 | 173 | 0.77 |
| 4 | DB | 728 | 23 | 0.97 |
| | DB Avg. | 647 | 104 | 0.86 |
| 5 | DL | 331 | 420 | 0.44 |
| 6 | DL | 267 | 484 | 0.36 |
| 7 | DL | 254 | 497 | 0.34 |
| 8 | DL | 312 | 439 | 0.42 |
| | DL Avg. | 291 | 460 | 0.39 |
| 9 | ILB | 559 | 192 | 0.74 |
| 10 | ILB | 554 | 197 | 0.74 |
| | ILB Avg. | 556.5 | 194.5 | 0.74 |
| 11 | OL | 766 | 19 | 0.98 |
| 12 | OL | 615 | 170 | 0.78 |
| 13 | OL | 612 | 173 | 0.78 |
| 14 | OL | 619 | 166 | 0.79 |

| | | | | |
|---|---|---|---|---|
| | OL Avg. | 653 | 132 | 0.83 |
| 15 | OLB | 426 | 325 | 0.57 |
| 16 | OLB | 684 | 67 | 0.91 |
| | OLB Avg. | 555 | 196 | 0.74 |
| 17 | QB | 729 | 56 | 0.93 |
| 18 | RB | 513 | 272 | 0.65 |
| 19 | TE | 525 | 260 | 0.67 |
| 20 | WR | 391 | 394 | 0.50 |
| 21 | WR | 575 | 210 | 0.73 |
| 22 | WR | 548 | 237 | 0.70 |
| | WR Avg. | 504.7 | 280.3 | 0.64 |

DB: Defensive back; DL: Defensive linemen; ILB: Inside linebacker; OL: Offensive linemen; OLB: Outside linebacker; QB: Quarterback; RB: Running back; TE: Tight end; WR: Wide receiver

## 3.3 PROCEDURES

GPS monitors (MinimaxX S5; Catapult Innovations, Melbourne, Australia) were used to measure the in-play and out-of-play competition demands of collegiate American football. The monitors utilized a 10 Hz sampling frequency. The use of GPS to quantify the physical game demands has previously been deemed valid and reliable [8, 16-19]. Each athlete was equipped with the same GPS monitor for each activity that was recorded over the course of the season. All participants had experience wearing the monitors in the four weeks of football-specific training prior to the first competition. All competitions were played outdoors between the months of September and November between 12:00 and 22:00 EST. Each competition consisted of four quarters lasting 15-minutes, with a brief intermission between quarters for a total duration of approximately three hours and twenty minutes per game. The participants of the study were divided into specific position groups. The offensive position groups included offensive lineman (OL), tight ends (TE), wide receivers (WR), running backs (RB), and quarterbacks (QB). The defensive position groups included defensive lineman (DL), outside linebackers (OLB), inside linebackers (ILB), and defensive backs (DB).

Before each competition, GPS monitors were placed into secure pouches on the posterior side of custom-fit shoulder pads between the participant's shoulder blades. Using the Openfield software, alarms were set for each unit, initiating data collection 15 minutes before the start of each competition. Once initiated, a GPS unit collected data while it was in communication with at least four satellites. Each GPS monitor was retrieved from the participant's shoulder pads at the conclusion of each game and inserted into a charging dock. The data were then downloaded to the Openfield software. After the download was completed, the game video was downloaded and synced to the GPS data recorded during the competition. The start time of the first play was used to sync the video and GPS data. The video was only used as a guide to validate when a play occurred. The velocity tracings provided by the Openfield software were used to break down the GPS data into individual "periods" when plays occurred. The players who participated in a specific play were added to the coinciding "period" using the velocity tracings provided in the Openfield software and validated using Pro Football Focus (PFF) data. Once analyzed, only the data recorded during the specific time period were analyzed for the athletes that participated in the play. This process was repeated for each play during a competition. Next, a full activity "period" was created for the entire competition. This "period" began at the onset of the first play of the game and ended at the conclusion of the final play of the game. The full activity "period" provided all the GPS data recorded during the game for each athlete. This process was repeated for each competition. All data collected from special teams plays, QB kneeling plays, QB spike plays, and plays with pre-snap penalties (i.e., false start) were excluded from the analysis.

The GPS variables analyzed in this study utilized relative speed zones to determine the distances traveled at different velocities. Relative speed zones were used because of the differences in running velocities observed between lineman (OL and DL) and non-lineman (WR, DB, RB, QB, ILB, and OLB) during the summer strength and conditioning protocol. Specifically, all participants participated in linear sprint training during the 8-week summer strength and conditioning protocol. The values recorded for maximal running velocity during the training sessions were used to determine the relative speed zones for each participant. The variables analyzed in the study include standing distance (m), walking distance (m), jogging distance (m), extensive tempo distance (m), intensive tempo distance (m), sprint distance, total distance (m), and intensity (m/min). A description of the relative velocity zones is provided in Table 3. Previous research pertaining to American football has not used relative speed zones. The performance coaches of the University implemented the designated percentages.

Table 3.3 Relative velocity zone classifications.

| Movement classification | Relative Maximum Velocity | | |
|---|---|---|---|
| Standing (m) | 0 | - | 4.90% |
| Walking (m) | 5 | - | 19.90% |
| Jogging (m) | 20 | - | 49.90% |
| Extensive tempo (m) | 50 | - | 71.90% |
| Intensive tempo (m) | 72 | - | 89.90% |
| Sprint (m) | 90 | - | 100% |

## 3.4 STATISTICAL ANALYSIS

Before a comparison could be made between the in-play and out-of-play GPS variables, out-of-play distances were determined. Specifically, to determine the distances out-of-play, the sum of in-play GPS variables was subtracted from the outcomes that were determined from the full activity "period." Collectively, this identified the total distance and distances traveled in all relative speed zones that occurred in-play and out-of-play. The mean and standard deviation values of in-play and out-of-play distances were reported for each participant across all position groups for all games. Difference scores of the mean total and relative distances were calculated for each participant and position group as: absolute value of (mean out-of-play variables – mean in play variables) Sample distributions were assessed via Fisher's Coefficient of Skewness (Skewness / Standard Error of Skewness) for each position. A coefficient greater than the absolute value of 1.96 was considered to be skewed. Paired samples T-tests were used to determine if there was a difference between in-play and out-of-play variables. The relative composition of in-play GPS metrics relative to the total game GPS metrics were calculated as: (in-play GPS variable / total game GPS variable). The level of significance was set at $p \leq 0.05$ for all analyses. Cohen’s effect sizes were reported for all in-play versus out-of-play variables and were defined as follows: Small effect: 0.20-0.49; Moderate effect: 0.50-0.79; Large effect: $\geq 0.80$. The statistical analysis was performed using IBM Statistical Package for the Social Sciences (SPSS for Windows 28.0; SPSS, Inc., Chicago, IL, USA).

# CHAPTER 4: RESULTS

The mean and standard deviation were reported for the total duration, total distance, standing distance, walking distance, jogging distance, extensive tempo distance, intensive tempo distance, sprint distance, and intensity at each position group. The in-play GPS outcomes stratified by position are displayed in Tables 4 and 5. The out-of-play position outcomes are shown in Tables 6 and 7. Mean difference scores were provided for each variable at each position group. For the DL and OL position groups, there was no mean difference score reported for sprint distance because the average sprint distance at each position was 0 m. The mean difference scores of each position are displayed in Table 8.

Table 4.1 Descriptive in-play competition global positioning system outcomes (per game) in defensive position groups.

| GPS classification | DB (n=4) | DL (n=4) | ILB (n=2) | OLB (n=2) |
|---|---|---|---|---|
| Total duration (min) | 6.4 ± 1.8 | 2.9 ± 1.1 | 5.3 ± 1.5 | 5.7 ± 1.8 |
| Total distance (m) | 1111.5 ± 296.6 | 371.2 ± 136.4 | 868.1 ± 220.5 | 883.4 ± 272.8 |
| Standing distance (m) | 26.2 ± 12.1 | 16.5 ± 8.2 | 29.8 ± 12.0 | 33.0 ± 12.4 |
| Walking distance (m) | 172.6 ± 54.7 | 90.2 ± 37.4 | 137.9 ± 38.4 | 157.1 ± 51.1 |
| Jogging distance (m) | 575.3 ± 140.4 | 210.1 ± 73.7 | 452.9 ± 123.6 | 516.4 ± 159.4 |
| Extensive tempo distance (m) | 270.3 ± 107.1 | 47.0 ± 29.3 | 201.9 ± 53.9 | 151.6 ± 59.5 |
| Intensive tempo distance (m) | 57.8 ± 36.8 | 5.6 ± 9.3* | 38.8 ± 23.4 | 20.1 ± 20.2 |
| Sprint distance (m) | 3.0 ± 9.1 | 0.0 ± 0.0 | 2.6 ± 7.8 | 0.7 ± 3.0* |
| Intensity (m/min) | 177.0 ± 18.9 | 129.9 ± 16.4 | 165.7 ± 15.9 | 154.8 ± 13.7 |

DB: Defensive back; DL: Defensive linemen; ILB: Inside linebacker; OLB: Outside linebacker.
*Indicates a Fisher's coefficient of skewness greater than the absolute value of 1.96.
Values represent mean ± standard deviation.

Table 4.2 Descriptive in-play competition global positioning system outcomes (per game) in offensive position groups.

| GPS classification | OL (n=4) | QB (n=1) | RB (n=1) | TE (n=1) | WR (n=3) |
|---|---|---|---|---|---|
| Total duration (min) | 6.3 ± 1.3 | 6.9 ± 0.8 | 4.8 ± 1.3 | 4.9 ± 0.6 | 4.9 ± 1.4 |
| Total distance (m) | 698.3 ± 137.2 | 860.7 ± 107.7 | 748.9 ± 195.7 | 699.5 ± 92.6 | 900.2 ± 267.2 |
| Standing distance (m) | 40.1 ± 11.0 | 70.0 ± 8.9 | 38.1 ± 14.4 | 43.6 ± 5.4 | 41.2 ± 12.7 |
| Walking distance (m) | 211.8 ± 46.6 | 252.7 ± 38.6 | 126.4 ± 47.6 | 152.2 ± 22.3 | 99.9 ± 30.1 |
| Jogging distance (m) | 403.9 ± 89.3 | 356.3 ± 55.6 | 371.1 ± 97.7 | 352.1 ± 63.5 | 379.4 ± 113.6 |
| Extensive tempo distance (m) | 35.9 ± 20.8 | 123.5 ± 42.5 | 174.8 ± 54.2 | 130.3 ± 40.8 | 269.2 ± 104.0 |
| Intensive tempo distance (m) | 2.9 ± 7.6* | 51.3 ± 24.1 | 31.3 ± 18.8 | 15.3 ± 12.9 | 97.9 ± 63.8 |
| Sprint distance (m) | 0.0 ± 0.0 | 1.8 ± 3.7 | 1.4 ± 3.3* | 0.6 ± 1.9* | 8.3 ± 14.4 |
| Intensity (m/min) | 111.5 ± 8.6 | 125.2 ± 11.7 | 158.3 ± 14.5 | 142.4 ± 10.7 | 185.0 ± 18.7 |

OL: Offensive linemen; QB: Quarterback; RB: Running back; TE: Tight end; WR: Wide receiver.
*Indicates a Fisher's coefficient of skewness greater than the absolute value of 1.96.
Values represent mean ± standard deviation.

Table 4.3 Descriptive out-of-play competition global positioning system outcomes (per game) in defensive position groups.

| GPS classification | DB (n=4) | | | DL (n=4) | | | ILB (n=2) | | | OLB (n=2) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total duration (min) | 192.0 | ± | 10.9 | 195.7 | ± | 11.4 | 193.4 | ± | 11.3 | 192.6 | ± | 11.5 |
| Total distance (m) | 3355.0 | ± | 794.2 | 1771.9 | ± | 420.8 | 3867.3 | ± | 799.0 | 3294.4 | ± | 496.4 |
| Standing distance (m) | 538.5 | ± | 138.9 | 333.1 | ± | 93.9 | 701.5 | ± | 151.1 | 519.5 | ± | 121.4 |
| Walking distance (m) | 2216.7 | ± | 596.7 | 1109.6 | ± | 268.4 | 2439.0 | ± | 562.9 | 1872.4 | ± | 335.8 |
| Jogging distance (m) | 563.1 | ± | 202.4 | 316.8 | ± | 136.3 | 667.2 | ± | 203.6 | 831.5 | ± | 262.5 |
| Extensive tempo distance (m) | 39.5 | ± | 29.1 | 13.8 | ± | 15.2 | 61.6 | ± | 40.0 | 70.1 | ± | 64.0 |
| Intensive tempo distance (m) | 2.3 | ± | 5.7* | 0.0 | ± | 0.2* | 1.2 | ± | 3.2* | 5.3 | ± | 8.2* |
| Sprint distance (m) | 0.4 | ± | 2.5* | 0.0 | ± | 0.0 | 0.3 | ± | 1.2* | 0.1 | ± | 0.3* |
| Intensity (m/min) | 17.5 | ± | 3.9 | 9.1 | ± | 2.1 | 20.0 | ± | 3.8 | 17.1 | ± | 2.3 |

DB: Defensive back; DL: Defensive linemen; ILB: Inside linebacker; OLB: Outside linebacker.
*Indicates a Fisher's coefficient of skewness greater than the absolute value of 1.96.
Values represent mean ± standard deviation.

Table 4.4 Descriptive out-of-play competition global positioning system outcomes (per game) in offensive position groups.

| GPS classification | OL (n=4) | | | QB (n=1) | | | RB (n=1) | | | TE (n=1) | | | WR (n=3) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total duration (min) | 192.2 | ± | 11.2 | 191.8 | ± | 11.7 | 193.9 | ± | 11.9 | 193.3 | ± | 11.8 | 193.5 | ± | 11.6 |
| Total distance (m) | 2129.7 | ± | 421.5 | 3423.8 | ± | 346.9 | 2600.1 | ± | 642.7 | 4544.8 | ± | 497.1 | 3223.8 | ± | 672.0 |
| Standing distance (m) | 303.9 | ± | 76.4 | 670.7 | ± | 107.2 | 591.4 | ± | 165.3 | 570.1 | ± | 86.4 | 575.4 | ± | 147.7 |
| Walking distance (m) | 1328.0 | ± | 358.3 | 2036.8 | ± | 232.0 | 1613.2 | ± | 404.1 | 2953.8 | ± | 429.1 | 1789.7 | ± | 415.6 |
| Jogging distance (m) | 490.1 | ± | 147.0 | 681.6 | ± | 148.9 | 355.0 | ± | 139.4 | 910.0 | ± | 175.0 | 795.0 | ± | 245.3 |
| Extensive tempo distance (m) | 11.0 | ± | 14.8 | 31.4 | ± | 27.6 | 37.0 | ± | 33.6 | 100.1 | ± | 53.7 | 55.1 | ± | 41.9 |
| Intensive tempo distance (m) | 0.2 | ± | 0.8* | 5.8 | ± | 13.8* | 3.5 | ± | 6.3 | 15.3 | ± | 17.6 | 10.8 | ± | 17.2 |
| Sprint distance (m) | 0.0 | ± | 0.0 | 1.7 | ± | 5.8* | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 | 1.9 | ± | 9.9* |
| Intensity (m/min) | 11.1 | ± | 2.1 | 17.9 | ± | 1.5 | 13.5 | ± | 3.5 | 23.6 | ± | 2.5 | 16.7 | ± | 3.6 |

OL: Offensive linemen; QB: Quarterback; RB: Running back; TE: Tight end; WR: Wide receiver.
*Indicates a Fisher's coefficient of skewness greater than the absolute value of 1.96.
Values represent mean ± standard deviation.

Table 4.5 Mean differences between in-play and out-of-play competition global positioning system metrics in 22 collegiate American football players.

| GPS classification | DB (n=4) | DL (n=4) | ILB (n=2) | OL (n=2) | OLB (n=2) | QB (n=1) | RB (n=1) | TE (n=1) | WR (n=1) |
|---|---|---|---|---|---|---|---|---|---|
| Total duration (min) | 185.6 | 192.8 | 188.1 | 185.9 | 186.8 | 184.9 | 189.1 | 188.4 | 188.7 |
| Total distance (m) | 2243.5 | 1400.7 | 2999.2 | 1431.4 | 2411.0 | 2563.1 | 1851.2 | 3845.3 | 2323.7 |
| Standing distance (m) | 512.3 | 316.6 | 671.7 | 263.9 | 486.5 | 600.6 | 553.3 | 526.4 | 534.2 |
| Walking distance (m) | 2044.0 | 1019.4 | 2301.1 | 1116.2 | 1715.3 | 1784.1 | 1486.8 | 2801.6 | 1689.8 |
| Jogging distance (m) | -12.3 | 106.8 | 214.3 | 86.1 | 315.2 | 325.3 | -16.1 | 557.9 | 415.7 |
| Extensive tempo distance (m) | -230.8 | -33.2 | -140.3 | -24.9 | -81.6 | -92.1 | -137.8 | -30.3 | -214.1 |
| Intensive Tempo distance (m) | -55.5 | -5.6 | -37.6 | -2.7 | -14.8 | -45.5 | -27.8 | 0.0 | -87.2 |
| Sprint distance (m) | -2.6 | 0.0 | -2.3 | 0.0 | -0.6 | -0.2 | -1.4 | -0.6 | -6.5 |
| Intensity (m/min) | -159.6 | -120.8 | -145.7 | -100.4 | -137.7 | -107.3 | -144.8 | -118.8 | -168.3 |

Difference scores were calculated as: (out-of-play variables – in-play variable). Negative values indicate that the mean in-play variable was greater than the mean out-of-play variable.
DB: Defensive back; DL: Defensive linemen; ILB: Inside linebacker; OL: Offensive linemen; OLB: Outside linebacker; QB: Quarterback; RB: Running back; TE: Tight end; WR: Wide receiver.

The in-play total duration, total distance, standing distance, walking distance, and jogging distance were significantly ($p < 0.001$) lesser than the out-of-play counterparts. Conversely, the in-play extensive tempo distance, intensive tempo distance, sprint distance, and intensity were significantly ($p < 0.001$) larger than the out-of-play counterparts. Large effect sizes were observed for the total duration, total distance, standing distance, walking distance, extensive tempo distance, and intensity. Moderate effect sizes were observed for jogging distance and intensive tempo distance. Small effect sizes were observed for the sprint distance. Comparison of means and Cohens effect sizes are shown in Table 9.

Table 4.6 Comparison of mean competition in-play versus out-of-play global positioning metrics in all participants (N=22).

| GPS classification | In-play | Out-of-play | Relative in-play outcome (Percentage of total (%)) | Effect size | Power |
|---|---|---|---|---|---|
| Total duration (min) | 5.2* | 193.2 | 2.6 | -16.63 | 1.00 |
| Total distance (m) | 782.6* | 2888.1 | 19.9 | -2.57 | 1.00 |
| Standing distance (m) | 33.2* | 486.5 | 5.8 | -2.56 | 1.00 |
| Walking distance (m) | 150.6* | 1782.6 | 7.2 | -2.53 | 1.00 |
| Jogging distance (m) | 404.2* | 579.9 | 39.4 | -0.69 | 1.00 |
| Extensive tempo distance (m) | 152.8* | 38.6 | 75.4 | 1.01 | 1.00 |
| Intensive tempo distance (m) | 35.31* | 3.6 | 87.0 | 0.73 | 1.00 |
| Sprint distance (m) | 2.2* | 0.4 | 85.7 | 0.20 | 0.48 |
| Intensity (m/min) | 149.9* | 15.0 | | 4.71 | 1.00 |

*Indicates significant difference between in-play versus out-of-play variables. ($p < 0.001$).
Relative in-play outcome (Percentage of total (%)) were calculated as: ((in-play variables / total game variables) x 100).

# CHAPTER 5: DISCUSSION

The primary purpose of this study was to utilize GPS technology to quantify the in-play competition demands of American collegiate football and to compare in-play versus out-of-play GPS outcomes. The primary finding from this study demonstrated that the total in-play distance was significantly less than the total out-of-play distance, the in-play distance traveled at higher velocities was significantly greater than the out-of-play distance traveled at higher velocities, and the in-play intensity was significantly higher than out-of-play intensity. The findings also demonstrate there was a significantly lower distance traveled in-play at lower velocities than out-of-play distances traveled at lower velocities. These results suggest that previous methods of quantifying competition demands in American football overestimate the total volume and underestimate the intensity of competition.

It should be noted that the findings of the present study do not suggest that the out-of-play GPS demands should be excluded from the total competition demands of American football. Instead, the results indicate that the out-of-play demands of American football differ from the demands when an athlete is actively competing with opponents in-play. The portion of American football where athletes are actively competing with opponents is when touchdowns are scored, tackles are made, and turnovers are forced. The performance outcomes that separate good players from bad players are measured in-play. With that in mind, the training for American football should be centered around optimizing in-play performance. From a bioenergetic standpoint, the out-of-play demands provide valuable information to the passive and active recovery between plays, series, and quarters, but not to the portion of the game where performance outcomes are measured.

Previous research has reported the total game demands by position using GPS [4, 5] Although informative, this does not provide an accurate description of the competition demands of American football. The results observed in the present study are similar to the results observed by Wellman et al., when analyzed in the same fashion [4]. If the average total distance traveled per game in the present study is calculated by summing the in-play and out-of-play distance for each position, the values observed are comparative to those by Wellman and colleagues [4]. The total distance for the DB and RB positions are the most similar with less than 300 m difference at each position. The present study observed that the average DB, DL, OL, and WR covered less distance, while the average ILB, OLB, QB, RB and TE covered more distance when compared to the results provided by Wellman et al, [4]. It is unusual that the present study observed some positional averages to be larger than those observed by Wellman and colleagues because of less stringent participation requirements, exclusion of special teams plays, exclusion of QB kneeling plays, exclusion QB spike plays, and exclusion of plays with pre-snap penalties in the present study. However, those differences could be due to differences in strategic play style between the two teams being analyzed. The similarities in total distance of the entire game across all positions could indicate that Wellman and colleagues would observe similar results to the present study if the game was analyzed in the same fashion.

There were several limitations to the present study. First, the present study analyzed all athletes collectively instead of by position. Due to the lack of participants available for analysis, it was the only method that could be used to make an accurate comparison. The substitution patterns made it difficult to have both an adequate number of plays participated in and multiple participants at each position. Previous research [4] surrounding competition demands of American football using GPS had more participants that allowed for comparisons to be made between position groups. The results show that positional differences can be attributed to in-play and out-of-play factors when analyzed across the entire game without benching athletes [4]. The method used to determine maximum velocity was another limitation of the present study. Athletes were not wearing shoulder pads or helmets when maximum velocities were determined during linear sprint training. The added weight of shoulder pads and helmets could inhibit athletes from reaching maximal velocity during competition. Therefore, the distances traveled in relative speed zones could be under reported in higher velocity zones. Another possible limitation of the study is solely using GPS variables to quantify game demands. The intermittent nature of American football requires athletes to accelerate at the onset of each play and decelerate when changing directions in-play. The accelerations and decelerations that occur in-play contribute to distances traveled at lower velocities. Although GPS measurements are being recorded as distance traveled in lower velocity zones, athletes are still increasing speed with the intention of reaching near maximal velocity when accelerating. In most cases, contextual factors limit an athlete's ability to reach near maximal velocities (i.e., QB, RB, TE, and WR changing directions to create space and OL, DB, DL, ILB, OLB changing directs to close space). This can be supported by the minimal distances traveled in intensive tempo and sprint velocity zones observed in Tables 4 and 5. While accelerating and decelerating, the lower extremities of

American football athletes are required to produce large amounts of force. Analyzing distances traveled in lower velocity zones without understanding the magnitude of accelerations and decelerations undervalues the amount of stress being placed on American football athletes in-play.

## 5.1 PRACTICAL APPLICATION

This study provides a novel analysis of the competition demands of American football using GPS. The information provided by the study sheds light on gaps in the previous literature surrounding the competition demands of American football. The analysis depicts the differences in GPS demands in-play versus out-of-play. The differences shown in-play and out-of-play in the study provide strength and conditioning and performance specialists with vital information about the GPS demands when performance outcomes are measured. The information provided can be used to increase the specificity of training and increase athletic performance for American football athletes.

Future research should examine positional differences at the play level in-play and out-of-play. Understanding the positional requirements at the play level will allow strength and conditioning and performance specialists to specify training for athletes even further. The information provided by this research could address the mechanical and bioenergetic demands of American football when implemented into training.

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