THE PHYSICAL DEMANDS OF 5 DISTINCT MESOCYCLES WITHIN A NCAA DIVISION I WOMEN'S COLLEGE SOCCER SEASON

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Abstract: Soccer is characterized as a high-intensity sport that combines intermittent bouts of anaerobic and aerobic activities such as jogging, shuffling, short sprints, rapid multi-directional acceleration and decelerations, turning, jumping, kicking, and tackling. Within the context of sports performance, an overarching goal of many teams is to develop and maintain optimal physical fitness throughout the course of the competitive season. In order to achieve this, one must fully understand the general and specific demands of their population's sport. Therefore, the purpose of this study was to investigate differences in internal and external training loads between 5 phases of a NCAA Division I women's soccer season. n total, 797 total data points from 80 games were analyzed from the current sample. A two-way Multivariate Analysis of Variance (MANOVA) was performed to analyze the effect of Position and Season Phase on internal and external loads. The MANOVA revealed no statistically significant interactions between the effects of Position and Season Phase on internal and external loads F(168, 5739) = 1.142, p = .103; Wilks' Λ = .781. Simple main effects analyses showed that Position (Defender, Midfielder, Forward) did have a statistically significant effect on internal and external loads F(42, 1524) = 7.694, p = .000; Wilks' Λ = .681. Additionally, large effect sizes were observed for this analysis ($\eta p^2 = 0.175$). Simple main effects analysis showed that Season Phase (Exhibition, Non-Conference, Conference, B12, NCAA) did have a statistically significant effect on internal and external loads F(84, 3012) = 3.785, p = .000; Wilks' Λ = .673. Additionally, a moderate effect size was observed for this analyses ($\eta p^2 = 0.094$). This study provides insight into the position- and season phase-specific physical demands of NCAA Division I women's soccer. The findings of this research successfully reconfirmed well-reported positional differences in physical demands. However, the current study has also successfully provided a novel contribution to the field by identifying the statistically significant differences in physical demands between specific phases of the NCAA Division I women's college soccer season. These findings may serve as a tool for assessing and enhancing current approaches to preparing female athletes for their respectful competitive seasons.

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CHAPTER I

INTRODUCTION

1.1 Introduction

Enjoyed by individuals of all ages, soccer is the world's most popular sport (Bangsbo, 1994). This, presumably, is due to the popularity of soccer from the recreational to the professional level. The nature of soccer is physically demanding due to the high number of sprints, changes of direction, jumps, tackles and technical actions including dribbling, shooting and passing (Nédélec, McCall, Carling, Legall, Berthoin, & Dupont, 2012). Throughout a soccer game, players perform approximately 1,000 of these different activities (Reilly, & Thomas, 1976). This equates to a change in some sort of physical or tactical activity occurring approximately every five seconds. Moreover, an examination of field players reveals the break-down of the movements during a match consists of approximately 36% jogging, 24% walking, 20% cruising, 11% sprinting, and 7% back pedaling with only 2% of the match actually with the ball (Reilly, & Thomas, 1976). Considering the variety of physical demands placed upon athletes throughout a match it seems that it would, in turn, elicit a variety of energetic demands which also contribute to overall energy expenditure (Reily, 1997).

The average distance covered in a given soccer match is between 10 to 13 kilometers for the professional male and female soccer player (Andersson et al., 2010; Bangsbo, 1994b; Mohr et al., 2003). Additionally, it has been demonstrated that although the majority of the distance covered in a game (80% - 90%) is at a lower intensity; the amount of high-intensity exercise separates top-class players from players of a lower standard (Andersson et al., 2010; Bangsbo, 1994b; Mohr et al., 2003). Many of the pertinent moments in a game are executed when a player is sprinting, jumping, accelerating, or changing direction at high speed. It has been suggested that the ability to accelerate quickly over short distances and change directions are the two main factors that are characteristic of soccer players, distinguishing them from players in other levels of football (Reilly et al., 2000). Bloomfield et al. (2007) was one of the first to explore the detailed aspects of player movements during a match. Time spent completing specific movements within a match is evidence that training approaches need to be tailored to specific player's position and playing level.

From youth to international levels of play, women's soccer has over 29 million participants around the world across more than 141 countries (Bangsbo, 1994a). There are over 2 million registered female soccer players in the United States of America and Germany, which are two of the leading countries in the development of women's soccer (Bangsbo, 1994a). Although women's soccer has grown tremendously within the last decade and athletes have greater resources to prepare for competition at their disposal, research is lacking compared to their male counterparts. Recently, more research has been aimed at addressing gaps in the scientific literature on female players by focusing on the unique aspects of the women's game in regard to nutrition, physical characteristics, fatigue and recovery, and the physical demands during game play (Bangsob, 1994a and 1994b).

With the development of technology, the depth to which the physical demands of sports can be explored and analyzed has grown exponentially (Bourdon 2017; Burgess 2017; Haddad et al. 2017; Cardinale et al. 2017; Halson et al. 2014; Rebelo et al. 2012; Sands 2017; Heishman et al. 2018; Heishman et al. 2020; Manzi et al. 2010; Paulauskas et al. 2019; Sprague 2014; Roth 2019; Hugjiltu 199; Elloumi 2012; Gabbett 2011; Flatt et al. 2018; Ward et al. 2018; Gentles et al. 2018; Jeong et al. 2011; Malone et al. 2015; Oliveira et al. 2019; Scott et al. 2013; Strauss et al. 2018; Esco et al. 2014; Bradley et al. 2013; Ehrmann et al. 2016; Flatt et al. 2015; Huggins et al. 2020).

Generally, these physical demands are classified as either internal training loads (ITLs) or external training loads (ETLs) (Heishman et al. 2018; Heishman et al. 2020; Manzi et al. 2010; Paulauskas et al. 2019; Sprague 2014; Roth 2019; Hugjiltu 199; Elloumi 2012; Gabbett 2011; Flatt et al. 2018; Ward et al. 2018; Gentles et al. 2018; Jeong et al. 2011; Malone et al. 2015; Oliveira et al. 2019; Scott et al. 2013; Strauss et al. 2018; Esco et al. 2014; Rebelo et al. 2012; Bradley et al. 2013; Ehrmann et al. 2016; Flatt et al. 2015; Huggins et al. 2020). Generally ITLs measure the human body's reaction to exercise and often include average heart rate (HRavg), maximal heart rate (HRmax), heart rate zone (HRZ) duration, and an arbitrary training load (TL) score which helps athletes, coaches, and sport scientist better understand the intensity of an exercise event (Alexander et al. 2014; Martínez-Lagunas et al. 2014; Oliveira et al. 2019; Sausaman et al. 2019; Andrzejewski et al. 2016; Bangsbo et al. 2014; Bradley et al. 2014; Clarke et al. 2018; Datson et al. 2017; Jagim et al. 2020; Krustrup et al. 2005; Lockie et al. 2018; Silva et al. 2015). ETLs measure the amount of work completed by an athlete and can range from distances covered and the volume of sprints performed to the volume of weight lifted during a training session(Alexander et al. 2014; Martínez-Lagunas et al. 2014; Oliveira et al. 2019; Sausaman et al. 2019; Andrzejewski et al. 2016; Bangsbo et al. 2014; Bradley et al. 2014; Clarke et al. 2018; Datson et al. 2017; Jagim et al. 2020; Krustrup et al. 2005; Lockie et al. 2018; Silva et al. 2015). Many sport coaches and support staff are emphasizing a more scientific approach to both designing and monitoring training programs. Appropriate load monitoring can aid in determining whether an athlete is adapting to a training program and in minimizing the risk of developing non-functional overreaching, illness, and/or injury (Halson et al. 2014). Overall, a more effective understanding of the intensity of exercise events could lead to more successful training methods that will help players achieve a higher level of playing performance in a more efficient time span (Figure 1).

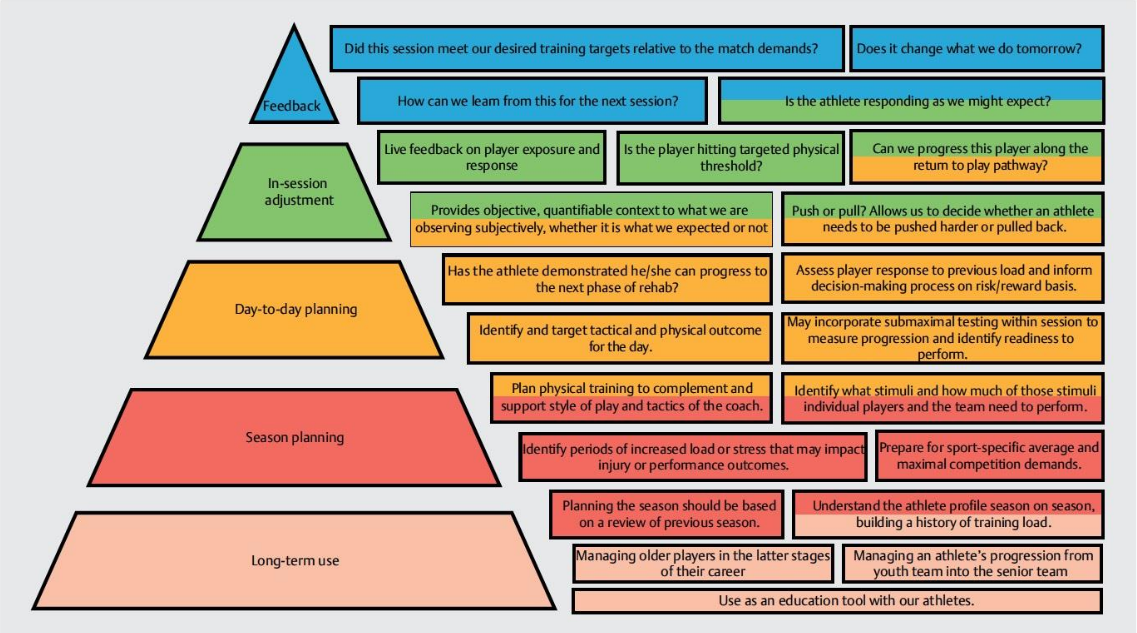

Figure 1. Five Levels at Which Training Load Informs Athlete Preparation (Adapted from West et al., (2020))

Being that a myriad of contextual factors can determine the success of an individual player and team, coaches are constantly searching for a better understanding of the physical demands of soccer (Figure 2.). For many decades the degree of stress and the physiological demands of soccer have been evaluated and the capability of the soccer players to meet these demands has been quantified (Strudwick, 2006). The quantification of these demands through the use of match and motion analysis has been restricted to the professional levels for many years due to lack of funding and resources at the lower levels. However, exploration of collegiate soccer's demands are becoming more pertinent because of the increasing injury rates in female soccer players (Agel et al., 2005). Just as important, bridging the gap from previously established values of physical demands presented for the women's professional level (Andersson et al., 2010; Mohr et al., 2008) and the youth level (Vescovi, 2014) would further promote the understanding of the differing demands at playing levels. Additionally, establishing these standards of physical performance at different playing levels would provide coaches with information to better train their players for the appropriate level at which they compete.

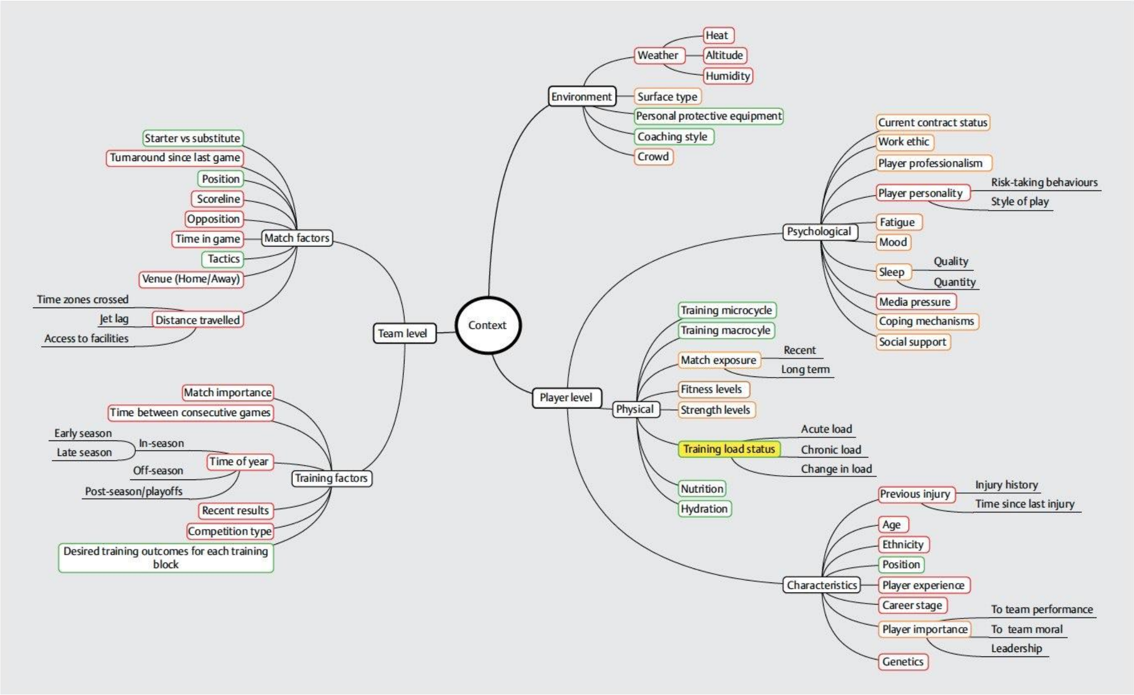

Figure 2. Contextual Factors of Managing Athlete Injury Risk and Readiness (Adapted from West et al., (2020))

Although previous studies have investigated short-term fluctuations in TLs within sports, no previous studies have examined these across longer periods of time. Additionally, fluctuations in TLs throughout the course of an entire competitive season, especially during distinct phases of competition are still unclear, and little evidence is available about how TLs may change as a result of these distinct phases. Therefore, analyzing the TLs throughout these distinct phases may lead to improved approaches for reducing injury risk, improving fitness, and optimizing performance.

1.2 Purpose of the Study

Although previous research has examined unique aspects concerning physical demands of women's soccer athletes, fluctuations in game demands throughout specific phases of a competitive season have not been completely elucidated. Thus, the purpose of this study was to investigate differences in ITLs and ETLs between 5 phases of 4 NCAA Division I women's soccer seasons.

1.3 Hypotheses and Research Questions

This study builds upon previous research and provide further insight into fluctuations in game demands throughout distinct mesocycles of an NCAA Division I women's soccer season. The aim of this investigation is to answer the following four research questions.

- Are there differences in internal training loads throughout the course of a soccer season?
    - Hypothesis: There are significant differences in internal training loads throughout specific phases of a soccer season
    - Hypothesis: There are differences in internal training loads throughout specific phases of a soccer season, but they are not significant.
- Are there differences in external training loads throughout the course of a soccer season?
    - Hypothesis: There are significant differences in external training loads throughout specific phases of a soccer season
    - Hypothesis: There are differences in external training loads throughout specific phases of a soccer season, but they are not significant.
    - Hypothesis: External training loads are equal throughout each specific phase of a soccer season.
- Are there significant differences in internal and external training loads throughout the course of a soccer season for specific position groups?

    - Hypothesis: No, there are not significant differences in internal and external training loads throughout the course of a soccer season for goalkeepers.
    - Hypothesis: No, there are not significant differences in internal and external training loads throughout the course of a soccer season for defenders.
    - Hypothesis: No, there are not significant differences in internal and external training loads throughout the course of a soccer season for midfielders.
    - Hypothesis: No, there are not significant differences in internal and external training loads throughout the course of a soccer season for forwards.
    - Hypothesis: Yes, there are significant differences in internal and external training loads throughout the course of a soccer season for goalkeepers.
    - Hypothesis: Yes, there are significant differences in internal and external training loads throughout the course of a soccer season for defenders.
    - Hypothesis: Yes, there are significant differences in internal and external training loads throughout the course of a soccer season for midfielders.
    - Hypothesis: Yes, there are significant differences in internal and external training loads throughout the course of a soccer season for forwards.

- If there are significant differences in internal and external training loads throughout the course of a soccer season, in which mesocycles do they occur?
    - Hypothesis: There are no significant differences in internal and external training loads throughout the course of season.

- Hypothesis: Internal and external training loads observed during the exhibition phase are significantly different when compared to other phases.
- Hypothesis: Internal and external training loads observed during the non-conference phase are significantly different when compared to other phases.
- Hypothesis: Internal and external training loads observed during the conference phase are significantly different when compared to other phases.
- Hypothesis: Internal and external training loads observed during the conference championship phase are significantly different when compared to other phases.
- Hypothesis: Internal and external training loads observed during the NCAA post-season tournament phase are significantly different when compared to other phases.

1.4 Significance of the Study

This study has the potential to enhance the current understanding of fluctuations in game demands across several identifiable phases of a NCAA Division I women's soccer season. The current literature has mostly focused on investigating player characteristics, individual game demands, and TL fluctuations over the course of a competitive women's soccer season, without providing a broad view of each variables place within the grand scheme of the season. Previous research into player characteristics has examined anthropometric, physical, and fitness properties of the women's soccer athlete, however, to our knowledge, there has been no other study that examined fluctuations in these properties during specific phases of the soccer season. Additionally, no other study has examined differences in soccer season phase demands represented by fluctuations in ITLs and ETLs. The proposed study could provide valuable information for improving coaching practices, strength and conditioning approaches, nutritional recommendations, and recovery modalities for optimizing athletic performance.

1.5 Delimitations

The following delimitations may affect the results and conclusions drawn in this study.

1. Archived data related to internal and external training loads for 116 NCAA Division I women's soccer athletes belonging to one team.
2. Data was provided to/accessed by the investigator between August 2020 and April 2022.
3. All identifiers were removed upon formal data entry. Subject numbers were used in place of names to maintain organization of the data.
4. The following internal and external training load variables were selected for descriptive and comparative purposes by the primary investigator: average heart rate, maximal heart rate, duration in heart rate zone one through five, training load score, caloric expenditure, total distance, distance in speed zones one through five, volume of sprints, number of accelerations and decelerations.
5. This study was limited to archival data voluntarily provided to the primary investigator via the team.
6. Participants were between the ages of 18-24 years old.
7. All participants were presumable healthy and free from any neuromuscular disease.

1.6 Limitations

The limitations in this study reflect the effect of the delimitations on the collection and interpretation of data and the ability to expand the scope of inference beyond the sample population. Generalizations made from the results will be comprised by the following limitations:

1. Participants were not randomly sampled.
2. Although phases were determined, several games within classified phases were more competitive, longer in duration, etc. than what can be presumably expected. Thus, final statistical analysis may be influenced by these differences.
3. There is missing data from some games due to equipment malfunctioning or failure to implement equipment, which is not uncommon within most athletic settings.
4. This study will use a non-invasive method of collecting data, therefore external factors may produce an increased variability in the data collected.

1.7 Assumptions

The following statements were assumed true when analyzing the results of this study.

1. The data provided to the primary investigator was true and accurate.
2. The equipment used to provide internal and external training load values is valid and reliable.
3. The equipment used to acquire all signals are calibrated and will be functioning properly.
4. There will be no errors in the data collection, data analysis, data entry or statistical evaluation process.

CHAPTER II

LITERATURE REVIEW

The following literature review will include previous research studies that are relevant to the purpose of this study. Each study will be summarized and the results of the study will be provided along with the interpretations of the authors. The aim of this review of the literature is to focus on providing background information about the variables assessed in the methods section of this dissertation. However, a few previous investigations have been included to highlight specific mechanisms related to the purpose of this proposed dissertation. After each section, there will be a brief summary of the articles.

As the competitive aspect of collegiate athletics increases, so too do the demands placed upon athletes. Aside from additional mental stress being placed upon athletes to perform at higher levels, their bodies are placed under a significant amount of stress especially during periods of competition. Due to participating in multiple sport practices, weightlifting sessions, and competitions while balancing academics, a social-life, and other miscellaneous factors, mitigating injury rates have become a primary concern for athletic staffs across the world (Bourdon et al., 2017; Burgess, 2017; Cardinale & Varley, 2017; Conte et al., 2018; Edwards et al., 2018; Ehrmann et al., 2016; Elloumi et al., 2012; Esco, Snarr, & Williford, 2014; Gabbett, Jenkins, & Sport, 2011; Haddad, Stylianides, Djaoui, Dellal, & Chamari, 2017; Halson, 2014;

Heishman et al., 2018; Heishman et al., 2020; Paulauskas et al., 2019; Sands et al., 2017). Thus, ITL and ETL monitoring was conceptualized.

Generally, TL monitoring takes into consideration the intensity and duration of training sessions or competitive events in order to provide quantitative values as feedback to the athlete and coaching staff (Haddad et al., 2017). While ITL primarily reflects the stress exercises places upon internal body systems (e.g. respiratory, cardiovascular, etc.), ETL reflects the external stress exercises places upon the body (e.g. distances covered, weights lifted, etc.) (Bourdon et al., 2017; Burgess et al., 2017; Cardinal et al., 2017; Haddad et al., 2017; Halson et al., 2014; Rebelo et al., 2012; Sands et al., 2017). Although there is a succinct division between the types of TL that can be monitored, there are ample ways to monitor it (Haddad et al., 2017; Halson, 2014; Heishman, 2018; Heishman, 2020; Hugjiltu, 1999).

2.1. Training Load Monitoring

2.1.1 TL Quantification without Technology/Equipment

Haddad et al. (2017)

This review of literature focused on common approaches for monitoring TL within athletic populations. The purpose of this review was to validate session rate of perceived exertion (sRPE) against common and often times more invasive methods used for measuring TL (i.e. HR, lactate threshold, etc.). 36 studies using the modified CR-10 were examined and confirmed the validity, reliability, and internal consistency of session-RPE method in several sports and physical activities with men and women of different age categories (children, adolescents, and adults) among various expertise levels. The modified CR-10 is a scale used to measure exercise intensity. Therefore, the authors concluded that this method could be used as a “stand alone” method for TL monitoring purposes, though some recommend combining it with other physiological parameters such as HR.

Elloumi et al. (2012)

As previous research suggests that sport coaches would benefit from a tool to assess TLs in order to avoid overtraining their athletes, the purpose of this study was to assess whether a short 8-item questionnaire of fatigue could be a useful tool for monitoring changes in perceived TL and strain among elite rugby Sevens (7s) players during preparation for a major competition. 16 elite rugby 7s players completed an 8-week training program composed of 6-week intense training (IT) and 2-week reduced training (RT). They were tested before (T0), after the IT (T1), and after the RT (T2). The quantification of the perceived TL and strain were performed by the sRPE method and concomitantly the 8-item questionnaire of fatigue was administered. TL and training strain (TS) and total score of fatigue (TSF from the 8-item questionnaire) increased during IT and decreased during RT. Simultaneously, physical performances decreased during IT and were improved after LT. The changes in TL, TS and TSF correlated significantly over the training period ($r=0.63-0.83$).

Gentles et al. (2018)

The purpose of this study was to use GPS, accelerometers, and session rating of perceived exertion (sRPE) to examine the demands of a Division II women's soccer team. Data was collected on 25 collegiate Division II women's soccer players over an entire regular season (17 matches and 24 practices). ITLs were assessed via sRPE. Mean Impulse Load, total distance, and sRPE during match play was 20,120 ± 8609 N·s, 5.48 ± 2.35 km, and 892.50 ± 358.50, respectively. Mean Impulse Load, total distance, and sRPE during practice was 12,410 ± 4067 N·s, 2.95 ± 0.95 km, and 143.30 ± 123.50, respectively. Several very large to nearly perfect correlations were found between Impulse Load and total distance ($r = 0.95$; $p < 0.001$), Impulse Load and sRPE ($r = 0.84$; $p < 0.001$), and total distance and sRPE ($r = 0.82$; $p < 0.001$). This study also demonstrates that sRPE is a valid, reliable, and consistent method for quantifying TL when compared to more invasive methods.

Jeong et al. (2011)

The aim of this study was to quantify the physiological loads of programmed "pre-season" and "in-season" training in professional soccer players. Data for players during each period were included for analysis (pre-season, n = 12; in-season, n = 10). TL was calculated by multiplying RPE score by the duration of training sessions. RPE was assessed via the Borg scale. The Borg scale is used to measure exercise intensity. Each session was sub-categorized as physical, technical/tactical, physical and technical/tactical training. Average physiological loads in pre-season (TL: 4343 ± 329 Borg scale · min) were significantly higher compared with in-season (TL 1703 ± 173 Borg scale · min) ($P < 0.05$). Such differences appear attributable to the higher intensities in technical/tactical sessions during pre-season (pre-season TL: 321 ± 23 Borg scale · min; in-season TL: 174 ± 27 Borg scale · min; $P < 0.05$). These findings demonstrate that pre-season training is more intense than in-season training. Additionally, these findings provide evidence that RPE is sensitive enough to detect significant fluctuations in TL throughout different phases of a competitive soccer season.

Malone et al. (2015)

The purpose of this study was to quantify the seasonal TL completed by professional soccer players of the English Premier League. Typical daily TL (i.e., RPE load) did not differ during each week of the preseason phase. Furthermore, TL was lower on the day before match (MD-1) than 2 (MD-2) to 5 (MD-5) d before a match, although no difference was apparent between these latter time points. The authors provided the 1st report of seasonal TL in elite soccer players and observed that periodization of TL was typically confined to MD-1 (regardless of mesocycle), whereas no differences were apparent during MD-2 to MD-5. Additionally, these findings are two-fold. First, they provided evidence that TL fluctuates throughout the week leading up to a match during a competitive soccer season. Second, they provided evidence that RPE is sensitive enough to detect those fluctuations in TL.

Manzi et al. (2010)

The aim of this study was to examine the TL profile of professional elite level basketball players during the crucial parts of the competitive season (e.g. pre-season, playoffs, and finals). Subjects were 8 full-time professional basketball players (age 28 ± 3.6 years, height 199 ±7.2 cm, body mass 102 ± 11.5 kg, and body fat 10.4 ± 1.5%) whose HR (HR) was recorded during each training session and their individual response to TL monitored using the session-rate of perceived exertion (RPE) method (200 training sessions). The association between the session-RPE method and training HR was used to assess the population validity of the session-RPE method. Significant relationships were observed between individual session-RPE and all individual HR-based TL (r values from 0.69 to 0.85; $p < 0.001$). Consequently, the importance of a practical and valid method to assess individual TL is warranted. In this research, the authors demonstrated that sRPE may be considered as a viable method to assess TL without the use of more sophisticated tools (i.e., HR monitors). The session-RPE method effectively detected the periodization patterns in weekly planning in elite professional basketball during the crucial part of the competitive season (1 vs. 2 weekly fixtures model).

Oliveira et al. (2019)

The aim of this study was to quantify internal and ETL within five microcycles: M1 and M2 – one-game weeks; M3 and M4 – two-game weeks; M5 – three-game week. Thirteen elite soccer players participated in this study. A global positioning system (GPS) was used to measure the total distance covered and distances of different exercise training zones (1–5) and the sRPE during daily training sessions for the 2015–2016 in-season period. The data were analysed with respect to the number of days prior to a given match. The main results indicate that there was a significant difference in training intensity for zone 1 between M2 and M4 (4010.2 ± 103.5 and 4507.6 ± 133.0 m, respectively); a significant difference in training intensity for zone 3 between M1 and M5 (686.1 ± 42.8 and 801.2 ± 61.2 m, respectively); a significant difference in the duration of the training sessions and matches between M2 and M5 (69.2 ± 2.1 and 79.6 ± 2.3) and M3 and M5 (69.7 ± 1.0 and 79.6 ± 2.3). Moreover, there was a significant decrease in TL in the last day prior to a match, for all microcycles and all variables. There was no significant difference with respect to s-RPE. This study provides the first report of daily external and ITLs and weekly accumulated load (training sessions and match demands) during one, two, and three-game week schedules in a group of elite soccer players. Expected significant differences are found in daily and accumulated loads for within- and between-game schedules. Overall, a similar pattern is exhibited for one- and two-game week microcycles regarding the day before the match, which exhibits a decrease in all variables. Despite the different number of games played per week, TL remained similar between microcycles for zone 2 and 5, plus s-RPE.

Scott et al. (2013)

The purpose of this study was to compare various measures of TL derived from physiological (HR), perceptual (sRPE), and physical (GPS and accelerometer) data during in-season field-based training for professional soccer. Physical measures of TD, LSA volume, and player load provided large, significant ($r = .71-.84$; $P < .01$) correlations with the HR-based and sRPE-based methods. Volume of HSR and VHSR provided moderate to large, significant ($r = .40-.67$; $P < .01$) correlations with measures of ITL. While the volume of HSR and VHSR provided significant relationships with ITL, physical-performance measures of TD, LSA volume, and player load appear to be more acceptable indicators of ETL, due to the greater magnitude of their correlations with measures of ITL. Overall, this study provided evidence that various methods for measuring TL are related and can provide insight into the intensity of exercise.

Rebelo et al. (2012)

The aim of this study was to evaluate the relationship between a new method to monitor TL in soccer (Visual Analogic Scale TL; VAS-TL), and two established HR-based methods (TRIMP and Edwards' method). 51 soccer players (age 15.6 ± 0.3 years) answered 2 questions to assess perceived exertion and fatigue (VAS1-TL, and VAS2-TL) after training sessions and official matches. Performance in the Yo-Yo tests, VAS scores and HR of training sessions and matches, and match activity were analysed. The authors found significant correlations ($r = 0.60$–0.72; $p < 0.05$) between VAS-TL, TRIMP, and the Edwards' TL method, with the highest correlations achieved in the matches. The new VAS-based perceived exertion method to monitor TL is easy to apply and is sensitive to differences in positional role and physical capacity. Thus, the applied method may be used in addition to the usual TL methods, allowing for daily quantification of individual TLs in soccer.

Casamichana et al. (2010)

The aim of this study was to examine physical, physiological, and motor responses and sRPE during different soccer drills. Participants were ten male youth soccer players. Each session comprised three small-sided game formats, which lasted 8 minutes each with a 5-minute passive rest period between them. A range of variables was recorded and analyzed for the three drills performed over three training sessions: (a) physiological, measured using Polar Team devices; (b) physical, using GPS SPI elite devices; (c) sRPE, rated using the CR-10 scale; and (d) motor response, evaluated using an observational tool that was specially designed for this study. Significant differences were observed for most of the variables studied. When the individual playing area was larger, the effective playing time, the physical (total distance covered; distances covered in low-intensity running, medium-intensity running, and high-intensity running; distance covered per minute; maximum speed; work-to-rest ratio; sprint frequency) and physiological TL (percent maximum HR; percent mean HR; time spent above 90% maximum HR), and the sRPE were all higher, while certain motor behaviors were observed less frequently (interception, control and dribble, control and shoot, clearance, and putting the ball in play). The results show that sRPE is equally as effective as more invasive methods for assessing physiological TL, or TL.

2.1.2 HR based TL Monitoring

Silva et al., 2015

The purpose of the first part of this project was to compare and contrast HR monitoring and session RPE as tools to assess ITL, specifically in soccer players. To that end, it seems that each method serves as valuable tool to assess the ITL of a player, but neither are without limitations and those should be considered carefully when deciding upon a method to be used to monitor TLs in soccer athletes. The purpose of the second portion of this project was to present a case study to design, execute, and evaluate the use of HR monitors as a tool for periodization in a Division I Men's Soccer team across a competitive season. The authors reported that there are three HR based TL calculations that are commonly used.

1. Bannister's Model of Monitoring TL (Silva, 2015)

The first of these three methods is Banister's training impulse (i.e., TRIMP). Banister's TRIMP can be quantified in a single term that balances exercise duration and intensity (Impellizzeri et al., 2005). This particular method uses the product of training session duration and average intensity of the training session and a sex-specific coefficient (Impellizzeri et al., 2005). Essentially, Banister's TRIMP is computed based-upon the mean exercise HR and duration of the exercise (Bannister, 1991). The specific formulas used for calculations can be found below.

TRIMP (Equation 1)

Men: duration (min) x (HRex – HRrest)/(HRmax – HRrest) x 0.64e 1.92x

Women: duration (min) x (HRex – HRrest)/(HRmax – HRrest) x 0.86e 1.67x

Where e = 2.712, x = (HRex – HRrest)/(HRmax – HRrest), HRrest = average HR during rest, and HRex = average HR during exercise (Banister)

There are several studies that demonstrate the utility of Banister’s TRIMP as a reliable measure of ITL. In professional male soccer players, across 29 exercise sessions Bannister’s TRIMP was found to be correlated with player load (r = 0.73) (Scott, Lockie, Knight, Clark, & De Jonge, 2013). Player load was determined as a result of individual player movements and accumulated accelerations (Scott, et al., 2013). Additionally, the total distance covered by each player was found to be positively correlated to Bannister’s TRIMP (Scott, et al., 2013). Another study compared the measurement of ITL on steady-state and interval-type exercise sessions (Wallace et al., 2013). Banister’s TRIMP was strongly positively correlated to total VO2 (Wallace et al., 2013). Additionally, Banister’s TRIMP produced significantly lower correlations with total VO2 compared to measures of HR alone when compared with percent VO2max (Wallace et al., 2013). The researchers suggest that these results could indicate that this method could be strong alternative method to quantify TL when ETL is not as clearly defined (Wallace et al., 2013).

Since TRIMP is computed based upon the mean exercise HR and duration of the exercise, it becomes a useful tool to measure TL in sports with intensities that are of an intermittent nature such as soccer (Bannister, 1991). The mean or average exercise HR is a reflection of the summation of every HR data point collected by the HR monitors (Bannister, 1991).

2. Edward's Model of Monitoring TL (Silva, 2015)

Some argue that using mean exercise HR is impractical to reflect the demands of long-duration, intermittent exercise such as team sports (Stagno, Thatcher & Van Someren, 2007). Thus, Banister's model has been modified to reflect the use of zones in which HR's time spent within each zone is accumulated (Foster et al., 2001). Edwards' method of quantifying TL is viewed as a progression of Bannister's model (Borresen & Lambert, 2008). In Edwards' model, the quantification of ITL is derived from duration spent within five different HR zones (Edwards, 1993). The zones represent percentages of HR max (50%-60%, 60%-70%, 70%-80%, 80%-90%, and 90%-100%). With the use of zones, it is suggested that since zones increase in a linear fashion, they are not reflective of exercise responses above an individual's anaerobic threshold (Wasserman, 1987). Therefore a weighting factor is needed for each zone (Stagno et al., 2007). In Edwards' model the duration in each zone is multiplied by the weighting factor which gives more weight to the higher intensity zones as compared to the lower intensity zones (Edwards, 1993). The product of these calculations is then summated to achieve a final score (Edwards, 1993). The formula used for calculating ITL using Edwards' model can be found below.

Summated-HR-zones method (Equation 2)

(duration in zone 1 x 1) + (duration in zone 2 x 2) + (duration in zone 3 x 3) + (duration in zone 4 x 4) + (duration in zone 5 x 5)

Where zone 1 = 50% to 60% of maximum HR, zone 2 = 60% to 70% HR max, zone 3 = 70% to 80% HR max, zone 4 = 80% to 90% HRmax, and zone 5 = 90% to 100% HR max (Edwards, 1993)

In addition to Banister's TRIMP, Edwards' TRIMP was found to have high positive correlations with player load (r = 0.73) and total individual distance covered in professional male soccer players (Scott, et al., 2013).

3. Lucia's Model of Monitoring TL (Silva, 2015)

Lucia's TRIMP is yet a further variation in which there are only three HR zones (zone 1 = below the ventilatory threshold, zone 2 = between the ventilatory threshold and respiratory-compensation point and zone 3 = above the respiratory-compensation point) (Lucia, 2003). The duration spent in each zone is multiplied by a coefficient (k) which is relative to each zone (k = 1 for zone 1, k = 2 for zone 2 and k = 3 for zone 3) (Lucia, 2003). These adjusted scores are then summated to acquire ITL (Lucia, 2003). Similar to Banister's TRIMP, Lucia's TRIMP has been found to be strongly positively correlated to total VO2 (Wallace et al., 2013). The researchers suggest that these results could indicate that these two methods could be strong alternative methods to quantify TL when ETL is not as clearly defined (Wallace et al., 2013).

Casamichana et al. (2010)

The aim of this study was to examine physical (i.e. distance, speed, etc.) and physiological responses (i.e. average HR, maximum HR, etc.) during different soccer drills. Participants were ten male youth soccer players. Each session comprised three small-sided game formats, which lasted 8 minutes each with a 5-minute passive rest period between them. Physiological and physical variables was recorded and analyzed for the three drills performed over three training sessions. Additionally, information regarding sRPE was also recorded and has been reported above. Significant differences were observed for most of the variables studied. When the individual playing area was larger, the effective playing time, the physical (total distance covered; distances covered in low-intensity running, medium-intensity running, and high-intensity running; distance covered per minute; maximum speed; work-to-rest ratio; sprint frequency) and physiological TL (percent maximum HR; percent mean HR; time spent above 90% maximum HR), were both higher. This study provides evidence that HR based TL monitoring is not only an adequate TL assessment tool, but it also appears to align well with physical efforts that may be of greater and lesser intensities.

Flatt et al. (2018)

The purpose of this study was to determine whether recovery of cardiac-autonomic activity to baseline occurs between consecutive-day training sessions among positional groups of a collegiate football team during spring camp. A secondary aim was to evaluate relationships between chronic (i.e., 4-week) HR variability (HRV) and TL parameters. Essentially, the authors reported that a capacity for greater chronic TLs may be protective against perturbations in cardiac-autonomic homeostasis among American college football players. Baseline HRV (lnRMSSD_BL) was compared with HRV after ∼20 hours of recovery before next-day training (lnRMSSDpost20) among positional groups composed of SKILL ($n = 11$), MID-SKILL ($n = 9$), and LINEMEN ($n = 5$) with a linear mixed model and effect sizes (ES). Players with greater body mass experienced larger reductions in lnRMSSD ($r = −0.62$, $p < 0.01$). Longitudinally, lnRMSSDcv was significantly related to body mass ($r = 0.48$) and PL_chronic ($r = −0.60$). After adjusting for body mass, lnRMSSDcv and PL_chronic remained significantly related ($r = −0.43$). The ∼20-hour recovery time between training sessions on consecutive days may not be adequate for restoration of cardiac-parasympathetic activity to baseline among linemen. Players with a lower chronic TL throughout camp experienced greater fluctuation in lnRMSSD (i.e., lnRMSSDcv) and vice versa.

Florida-James et al. (1995)

For at least the last 25 years, HR based TL monitoring has been used to assess sport demands across the course of a game. In the current study, match-day demands of Gaelic football and university competitive soccer player’s fitness profiles were assessed at club competitive level. English Gaelic football club championship players ($n = 11$) participated in this study and university competitive soccer players (n = 12) served as the reference group. HR was recorded during match-play using radio telemetry. For the Gaelic and soccer players, respectively, mean HR recorded during each half of match-play were (157 ± 10 and 158 ± 12 beats/min) and (164 ± 10 and 157 ± 11 beats/min). These findings are not only useful for showing HR based TL monitoring's propensity to detect changes in mean HR between each half of match-play, but also the fluidity of such assessment across different sports.

Jeong et al. (2011)

The aim of this study was to quantify the physiological loads of programmed "pre-season" and "in-season" training in professional soccer players. Data for players during each period were included for analysis (pre-season, n = 12; in-season, n = 10). TL was monitored by measuring HR and rating of perceived exertion (RPE). Information regarding sRPE measurements have been reported above in the "sRPE" section. Average physiological loads in pre-season (HR: 124 ± 7 beats · min−1) were higher compared with in-season (HR: 112 ± 7 beats · min−) ($P < 0.05$) and there was a greater portion of time spent in 80–100% maximum HR zones (18 ± 2 vs. 5 ± 2%; $P < 0.05$). Such differences appear attributable to the higher intensities in technical/tactical sessions during pre-season (pre-season: HR - 137 ± 8 beats · min−1; in-season: HR - 114 ± 9 beats · min−1; $P < 0.05$). These findings demonstrate that pre-season training is more intense than in-season training and that HR based TL monitoring can accurately detect these changes in intensity.

Malone et al. (2015)

The purpose of this study was to quantify the seasonal TL completed by professional soccer players of the English Premier League. Although, typical daily TL (ie, total distance, high-speed distance, percent maximal HR [%HRmax], RPE load) did not differ during each week of the preseason phase. %HRmax values were greater (3.3%, 1.3−5.4%) in the 3rd mesocycle than in the first. This study is self-proclaimed to be the first assess and identify seasonal TL differences in professional soccer. As such, HR based TL monitoring detected differences in seasonal TL while other more traditional TL assessment methods did not. Thus, when resources allow, HR based TL monitoring may be the best choice for monitoring fluctuations in TL.

Manzi et al. (2010)

The aim of this study was to examine the TL profile of professional elite level basketball players during the crucial parts of the competitive season. Subjects were 8 full-time professional basketball players (age 28 ± 3.6 years, height 199 ±7.2 cm, body mass 102 ± 11.5 kg, and body fat 10.4 ± 1.5%) whose HR was recorded during each training sessions and their individual response to TLs were monitored using the sRPE method over 200 training sessions. Overall, significant relationships were observed between individual sRPE and all individual HR-based TL (r values from 0.69 to 0.85; $p < 0.001$).

Rebelo et al. (2012)

The authors of this study stated that, “an accurate evaluation of TL is paramount for the planning and periodization of training”. Although the primary aim of the present study was to evaluate a new method of monitoring TL in soccer (Visual Analogic Scale TL; VAS-TL), two established HR-based methods (TRIMP and Edwards’ method) were also included within this study. In conclusion, it appears that both HR based TL monitoring methods used to monitor TL were correlated with the distance covered during the match ($r = 0.53$– 0.78; $p < 0.05$). These findings are important for further understanding how the demands of sport influence athlete’s body systems, and in turn, how those influences can be interpreted to understand and mitigate stress.

Scott et al. (2013)

To compare various measures of TL derived from physiological (HR), perceptual (sRPE), and physical (GPS) data during in-season field-based training for professional soccer. Physical measures of total distance, LSA volume, and player load provided large, significant ($r = .71-.84$; $P < .01$) correlations with the HR-based methods. Volume of HSR and VHSR provided moderate to large, significant ($r = .40-.67$; $P < .01$) correlations with measures of ITL as represented by differences in HR. In conclusion, these findings further support previous research by providing evidence of relationships between HR based TL monitoring methods physical measures.

2.1.3 Motion Characteristics as a Method for Monitoring TL

Casamichana et al. (2010) (overview and findings)

The aim of this study was to examine motor responses during different soccer drills in a group of ten male youth soccer players. Each session comprised three small-sided game formats, which lasted 8 minutes each with a 5-minute passive rest period between them. Motor responses were evaluated using an observational tool that was specially designed for this study. The authors observed significant differences for most of the variables studied. When the individual playing area was larger, the effective playing time and certain motor behaviors were observed less frequently. These motor behaviors included interception, control and dribble, control and shoot, clearance, and putting the ball in play. Thus, the opposite would be true for a smaller playing area where effective playing time and certain motor behaviors were observed more leading to higher TLs. The results show that the size of the pitch should be taken into account when planning training drills, as it influences the intensity of the task and the motor response of players. Additionally, motor responses may also be related to external factors such as playing area and event durations which contribute to variations in TL.

2.1.4 Lactate Threshold and Hormonal Analysis for Monitoring TL

Oliveira et al. (2019)

As mentioned previously, the aim of this study was to quantify internal and ETL within five microcycles. 13 elite soccer players participated in this study and the amount of CK created during daily training sessions for the 2015–2016 in-season period was measured. CK is an enzyme found in the heart, brain, skeletal muscle, and other tissues. Increased amounts of CK are released into the blood when there is muscle damage. Generally, muscle damage is associated with sprinting, jumping, lifting heavy weights etc. and it is a fairly common process during high level competition. After adequate rest and nutrition, the body is capable of repairing this damage. The data were analysed with respect to the number of days prior to a given match. The main results indicate that there was a significant difference in CK between M3 and M2 (325.5 ± 155.0 and 194.4 ± 48.9). Expected significant differences are found in daily and accumulated loads for within- and between-game schedules. A similar pattern is exhibited for one- and two-game week microcycles regarding the day before the match, which exhibits a decrease in all variables.

Florida-James et al. (1995)

Match-day demands of Gaelic football and fitness profiles were assessed at club competitive level. Blood lactate concentrations were determined at half-time and after full-time in a sample of 11 English Gaelic football club championship players. A similar test battery was administered to a reference group of University competitive soccer players (n = 12). Blood lactates measured at the end of each half, were (4.3 +/- 1 and 3.4 +/- 1.6 mmol/l) and (4.4 +/- 1.2 and 4.5 +/- 2.1 mmol/l).

Roth (2019)

The purpose of this study was to determine whether biological markers of muscle damage and inflammation coincide with subjective measures of muscle fatigue and sleep quality among Division I collegiate wrestlers. The goal was to provide practitioners with noninvasive techniques to evaluate a wrestler's inflammatory state. Biological measurements (CK, interleukin [IL]-6, tumor necrosis factor alpha [TNF-α], IL-1β, IL-10) and subjective measurements (fatigue, muscle soreness, and sleep quality) were performed. The self-reported level of muscle soreness and fatigue was significantly higher from pre-season through midseason, but leveled off late into the season. Creatine kinase followed a similar pattern early into the season compared with pre-season and decreased at the end of season. Plasma TNF-α and IL-8 levels increased modestly late into season compared with pre-season. These findings may indicate an adaptive response to the TL or a tapering of practice intensity in order to optimize performance. However, low-grade systemic inflammation increased late into the season, and correlated with poor sleep quality. Based on these findings, wrestlers may benefit by additional recovery time early into the season to prevent muscle fatigue and damage. As the season progresses, low-grade systemic inflammation may be prevented or monitored by tracking the quality of sleep and reiterating the importance of adequate sleep hygiene to athletes.

Hugjiltu (1999)

This study compared the resting serum hormones of control group(n =5) and male wrestlers(n =13).Testosterone(T), luteinizing hormone(LH),follicle stimulating hormone (FSH), prolactin (PRL) and cortisol (C) were measured by radioimmunoassay in resting blood samples (12h fast) collected pre-training and the second morning of last training. At the pre-training point, mean testosterone level was higher in wrestlers than in control group, while the other profiles were not different between both groups, but at the end of the training session (after 44 days), the resting T levels were lower in post-training than in pre-training, while C levels were high in post-training, but the levels of the other hormones were not changed. The changes of hormone levels were not related to hemoconcentration. There were significant correlations between T and C, PRL and LH. It's implied that exercise factors affected T and C, and non-exercise factors affected PRL and LH, separately. The results suggested normal hyperthalamic pituitary function existed in the trained subjects, and PRL, LH and FSH were not causative factors for the lowered testosterone levels. The findings indicated that high volume training stress lowers testosterone in wrestlers possibly by increasing cortisol and impairing testicular function. Additionally, monitoring serum hormones provides further insight into not only quantifying TL or stress, but also understanding how well athletes are recovering during very intense periods of training.

2.1.5 Summary of Training Load Monitoring

Monitoring internal and ETL within athletic populations provides athletic support staff with important information regarding the intensity of exercise, cumulative fatigue, and injury risks. Once collected and analyzed, this data can be used to guide decision-making regarding practice frequency, duration, and intensity, strength and conditioning approaches, nutrition recommendations, and recovery strategies. Additionally, previous research has shown that monitoring TL within an athletic population can be accomplished in a multitude of ways (Bourdon 2017; Burgess 2017; Cardinale et al. 2017; Haddad et al. 2017; Halson et al. 2014; Rebelo et al. 2012; Sands 2017). In this section of the literature review, four methods for monitoring TL were examined and proven to be accurate, reliable and actionable: 1.) TL monitoring without technology/equipment, 2.) HR-based TL monitoring, 3.) Motion characteristics as a method for monitoring TL, and 4.) lactate threshold and hormonal analysis as a method for monitoring TL.

Research regarding TL monitoring without the utilization of technology or technological equipment provided evidence that this method was accurate, reliable, and actionable (Casamichana et al. 2010; Elloumi et al. 2012; Gentles et al. 2018; Haddad et al. 2017; Jeong et al. 2011; Malone et al. 2015; Manzi et al. 2010; Oliveira et al. 2019; Rebelo et al. 2012; Scott et al. 2013). These methods are usually related to external factors and can be applied across multiple sports. Technology-free TL monitoring has been shown to accurately and reliably detect fluctuations in sRPE via the implementation of the CR-10 scale, TSF, and VAS-TL. The detected fluctuations in sRPE are representative of acute and chronic fatigue which may immediately or gradually affect performance, recovery, and preparedness. Although the feedback from this method provides actionable insights, it was not necessarily a stand-alone method for quantifying TL. In order to better guide-decision making, sport characteristics were often considered in addition to sRPE. These characteristics ranged from match congestion (number of games played within a calendar week) to training frequency and injury incidence. In addition to the time it takes to collect supporting characteristic data, tools which provide information about both, TL and sport characteristics may be preferred in most settings if their budget allows. Regardless, data regarding the relationships between the intensity of exercise and the subsequent fatigue is pertinent for adjusting practice frequency, duration, and intensity, strength and conditioning approaches, nutrition recommendations, and recovery strategies for optimizing performance, especially during high-intensity and/or highly-congested periods of a competitive season.

Research regarding the TL monitoring while utilizing technology-based methods were also accurate, reliable, and actionable (Casamichana et al. 2010; Flatt et al. 2018; Florida-James et al. 1995; Jeong et al. 2011; Malone et al. 2015; Manzi et al. 2010; Rebelo et al. 2012; Scott et al 2013; Silva et al. 2015). These methods usually account for internal and external factors which contribute to increased TLs. Similar to the conclusions drawn by previous research examining the effectiveness of TL monitoring without utilizing technology, technology based TL monitoring methods can also be applied across different sports in order to detect and monitor fluctuations in acute and chronic fatigue. However, there are several differences between the two methods. The first difference is that technology-based method are generally more expensive, but provide more detailed data and/or insights regarding specific aspects of fatigue, recovery, and fitness. The second difference is that in order to benefit from this technology, one must generally have access to internet/wifi, supporting technology (computers, laptops, printers, etc.) and understand the nuances of the software in order to sync and interpret data. Whereas not utilizing technology to monitor TL is simpler and more direct. This brings about the third difference which focuses on the reliability of technology when using HR monitors, motion characteristics, etc. in order to monitor TLs. First, without access to electricity, most technological devices will not work. Second, without access to a stable internet connection, TL data cannot be uploaded for analysis and interpretation. Third, devices utilized to monitor TL are often sensitive enough to detect subtle changes in HR and velocity. Such sensitive devices can also register false-positives in contact sports. This means that if the individual wearing the monitor or another individual makes forceful and direct contact with the monitor it may register an abnormally high HR or velocity which then affects the accuracy of the actual TL measure. Aside from these limitations, technology provides so much insight regarding the relationships between the intensity of exercise and the subsequent fatigue that is standard for most competitive soccer clubs to have in order to optimize performance, especially during high-intensity and/or highly-congested periods of a competitive season.

The most invasive methods of TL monitoring include lactate threshold and hormonal analysis for monitoring TL were also accurate, reliable, and actionable methods (Florida-James et al. 1995; Hugjiltu et al. 1999; Oliveira et al. 2019; Roth et al. 2019;). Although these methods generally require saliva or blood samples, they provide greater insight into changes at the molecular level in response to fluctuations in TLs. Additionally, they also take into account ITL factors such as HR max, duration in HR zone, etc. and external factors such as distance covered, max speed, practice frequency and intensity, etc. However, conducting this form of TL monitoring requires the assistance of a highly specialized individual (or group of individuals) who can conduct sample collection, analysis, and interpretation. Additionally, this method may be the most costly of the three different types of methods and require the most resources as well, which may not be sustainable for clubs and teams with smaller budgets.

2.2 Monitoring Training Load across Different Sports

2.2.1 Basketball Training Load Monitoring

Edwards et al. (2018)

There is currently limited research quantifying training or competition TL outside of time motion analysis in basketball. In addition, available research investigating methods to monitor and manage athlete fatigue in basketball throughout a season is scarce. To effectively optimize and maintain peak training and playing performance throughout a basketball season, potential TL and fatigue monitoring strategies need to be discussed. The sport of basketball exposes athletes to frequent high intensity movements including sprinting, jumping, accelerations, decelerations and changes of direction during training and competition which can lead to acute and accumulated chronic fatigue. Furthermore, fatigue may affect the ability of the athlete to perform over the course of a lengthy season.

Heishman et al. (2018)

As TL monitoring within basketball populations is grows, a wide-range of approaches are being utilized (Conte et al. 2018; Edwards et al. 2018; Heishman et al. 2018; Heishman et al. 2020; Manzi et al. 2010; Paulauskas et al. 2019). Elite male basketball imposes great physiological and psychological stress on players through training sessions and official competitions (1-2 per week) (Manzi et al. 2010). Consequently, the importance of a practical and valid method for assessing individual TL is warranted. The purpose of the present study was to assess the efficacy of external load and internal stress monitoring as assessment tools for examining a performance index of fatigue. A retrospective analysis was performed on data collected over the course of the preseason in 10 elite male NCAA Division 1 basketball players. Internal stress was assessed using Omegawave Technology readiness scores and compared with the performance index of countermovement jump (CMJ). The external load that accumulated during the previous practice, quantified by PlayerLoad (PL; Catapult), was compared with CMJ values and Omegawave scores. The results indicated that high, compared to low CNS Omegawave Readiness Scores (6.7 ± 05.1, 4.5 ± 1.2 AU; $p < 0.001$), were associated with increased CMJ (62.1 ± 6.5 vs. 59.4 ± 6.6 cm; $p = 0.05$), Power (6,590 ± 526.7 vs. 6,383.5 ± 606.8 W; $p = 0.05$), Omegawave Overall Readiness (5.8 ± 1.1 vs. 5.0 ± 0.7 AU; $p = 0.05$), and Omega Potential (Omega) (21.3 ± 6.3 vs. 9.9 ± 20.8 mV; $p = 0.07$). An increased PL during the previous exposure was associated with decreased CMJ (58.7 ± 4.7 cm vs. 60.4 ± 5.1 cm; $p < 0.001$) and increased TRIMP (135.1 ± 35.9 vs. 65.6 ± 20.0 AU; $p < 0.001$), and duration (115.4 ± 27.1 vs. 65.56 ± 20.0 minutes; $p = < 0.001$) despite no differences in Omegawave CNS Readiness scores. The authors concluded that Omegawave and Catapult technologies provide independent information related to performance and may be effective tools for monitoring athlete performance.

Heishman et al. (2020)

In a follow-up study, this investigation characterized ETL and CMJ performance changes across preseason training in Division 1 male collegiate basketball athletes, while examining the influence of position (Guard vs. Forward/Center) and scholarship status (Scholarship = S vs. Walk-on = WO). During 22 practices, ETL was monitored in 14 male athletes, with weekly CMJs performed to quantify neuromuscular performance (Jump Height [JH], Flight Time:Contraction

Time [FT:CT], Reactive Strength Index Modified [RSIMod]). PlayerLoad per minute was significantly higher during W1 and W2 (5.4 ± 1.3au and 5.3 ± 1.2au, respectively; $p < 0.05$) compared to subsequent weeks, but no additional differences in ETL parameters across time were observed. Scholarship athletes displayed greater PlayerLoad (S = 777.1 ± 35.6, WO = 530.1 ± 56.20; Inertial Movement Analysis (IMA) IMA High (S = 70.9 ± 15.2, WO = 41.3 ± 15.2); IMA Medium (S = 159.9 ± 30.7, WO = 92.7 ± 30.6); and IMA Low (S = 700.6 ± 105.1, WO = 405 ± 105.0;) ($p < 0.05$), with no observed differences in ETL by position. Moderate decreases in FT:CT and RSIMod paralleled increased ETL. Significant increases in practice intensity (W1 and W2) did not impact CMJ performance, suggesting athletes could cope with the prescribed TLs. However, moderate perturbations in FT:CT and RSIMod paralleled the weeks with intensified training. Cumulatively, scholarship status appears to influence ETL while player position does not.

Manzi et al. (2010)

The aim of this study was to examine the TL profile of professional elite level basketball players during the crucial parts of the competitive season (pre-, play-off, finals). The association between the sRPE method and training HR was used to assess the validity of the sRPE method. Significant relationships were observed between individual sRPE and all individual HR-based TL (r values from 0.69 to 0.85; $p < 0.001$). The individual weekly players' TL resulted in being not significantly different from each other ($p > 0.05$). This study was integral for demonstrating that sRPE may be considered as a viable method to asses TL without the use of more sophisticated tools (i.e., HR monitors).

Paulauskas et al. (2019)

The purpose of this study was to assess the weekly fluctuations in TL and differences in TL according to playing time in elite female basketball players across a competitive season. The highest changes in total weekly TL, weekly TL, and acute:chronic TL ratio were evident in week 13 (47%, 120%, and 49%, respectively). Chronic TL showed weekly changes ≤10%, whereas monotony and training strain registered highest fluctuations in weeks 17 (34%) and 15 (59%), respectively. A statistically significant difference in game loads was evident between players completing low and high playing times (P = .026, moderate), whereas no significant differences (P > .05) were found for all other dependent variables. Overall, the authors concluded that coaches of elite women's basketball teams should monitor weekly changes in TL during the in-season phase to identify weeks that may predispose players to unwanted spikes in TL and adjust player TL according to playing time.

Conte et al. (2018)

The purpose of this study was to characterize the weekly TL and well-being of college basketball players during the in-season phase. Total weekly TL and acute:chronic TL ratio demonstrated high week-to-week variation, with spikes up to 226% and 220%, respectively. Starting players experienced a higher (most likely negative) total weekly TL and similar (unclear) well-being status compared with bench players. However, the authors reported that game scheduling influenced TL, with 1-game weeks demonstrating a higher (likely negative) total weekly TL and similar (most likely trivial) well-being status compared with 2-game weeks. These findings provide college basketball coaches information to optimize training strategies during the in-season phase. It was stated that basketball coaches should concurrently consider the number of weekly games and player status (starting vs bench player) when creating individualized periodization plans, with increases in TL potentially needed in bench players, especially in 2-game weeks. Overall, monitoring total weekly TL and acute:chronic TL ratio appeared to provide clear insights into the stress occurred during a regular competitive season in the collegiate basketball population.

2.2.2 Volleyball Training Load Monitoring

Sprague (2014)

Aside from monitoring ITL and ETL, other methods for assessing TL fluctuations over the course of a competitive season are often implemented. The purpose of this study was to document the changes in functional movement patterns over a competitive season. 57 NCAA Division II athletes were screened using the FMS as part of the pre- and post-participation examination for their competitive seasons in 2012. Although, there were no significant interactions in the main effects for time or sport in the composite FMS scores. Four individual tests did show significant change. The deep squat ($Z = -3.260$, $p = 0.001$) and in-line lunge scores ($Z = -3.498$, $p < 0.001$) improved across all athletes, and the active straight leg raise ($Z = -2.496$, $p = 0.013$) and rotary stability scores ($Z = -2.530$, $p = 0.011$) worsened across all athletes. A reduction in the number of asymmetries ($\chi2 = 4.258$, $p = 0.039$) and scores of 1 ($\chi2 = 26.148$, $p < 0.001$) were also found. The authors concluded that changes in individual fundamental movement patterns occur through the course of a competitive season. While improvements may be attributable to specific strength and conditioning approaches to improve performance and mitigate risks, decreases may be more attributable to the compounded stresses of a competitive season.

2.2.3 Wrestling Training Load Monitoring

Roth (2019)

Although TL research regarding combat sports is often conducted via novel approaches, they provide useful information regarding athlete fatigue, preparedness, and recovery status. The purpose of this study was to determine whether biological markers of muscle damage and inflammation coincide with subjective measures of muscle fatigue and sleep quality among Division I collegiate wrestlers. The goal was to provide practitioners with noninvasive techniques to evaluate a wrestler's inflammatory state. Biological measurements (CK, IL-6, TNF-α, IL-1β, IL-10) and subjective measurements (fatigue, muscle soreness, and sleep quality) were performed. The authors found that self-reported level of muscle soreness and fatigue was significantly higher from pre-season through mid-season, but leveled off late into the season. CK followed a similar pattern early into the season compared with preseason and decreased at the end of season. Plasma TNF-α and IL-8 levels increased modestly late into season compared with preseason. This approach for assessing and quantifying TL fluctuations provides useful feedback to both, the coach and athlete concerning the allotment of additional recovery time early into the season in order to prevent muscle fatigue and damage. Additionally, the study also suggests that as the season progresses, low-grade inflammation may be prevented or monitored by tracking the quality of sleep. Altogether, these findings display the value of TL monitoring in athletic populations and how results can be applied to traditional approaches in order to improve athlete performance and mitigate fatigue.

Hugjiltu (1999)

This study compares the resting serum hormones of a control group (n =5) and male wrestlers (n =13). T, LH, FSH, PRL, and C were measured by radioimmunoassay in resting blood samples collected pre-training and the morning of the last training session. At the pre-training point, mean T level was higher in wrestlers than in control group, while the other profiles were not different between both groups. However, at the end of training camp (after 44 days), the resting T levels were lower in post-training than in pre-training, while C levels were high in post-training, the levels of the other hormones were not changed. The authors reported that changes of hormone levels were not related to hemoconcentration. Additionally, there were significant correlations between T and C, PRL and LH. This relationships imply that exercise affected T and C, and non-exercise affected PRL and LH, separately. The results suggested normal hyperthalamic pituitary function existed in the trained subjects, and PRL,LH and FSH were not causative factors for the lowered testosterone levels. The value in this study is that their findings indicated that high volume training stress lowers testosterone in wrestlers possibly by increasing cortisol and impairing testicular function.

2.2.4 Rugby Training Load Monitoring

Elloumi (2012)

The purpose of this study was to assess whether a short 8-item questionnaire of fatigue (TSF) could be a useful tool for monitoring changes in perceived TL and strain among elite rugby 7s players during preparation for a major competition. TL, TS, and TSF increased during IT and decreased during RT. Simultaneously, physical performances decreased during IT and were improved after LT. The changes in TL, TS and TSF correlated significantly over the training period (r=0.63-0.83). These findings provide evidence of the effectiveness of a multi-faceted approach for monitoring TL fluctuations over specific phases of competition preparation. Additionally, these findings also suggest that the short questionnaire of fatigue could be a practical and a sensitive tool for monitoring changes in TL and strain in team-sport athletes.

Gabbett (2011)

The purpose of this investigation was to investigate the relationship between TL and injury in professional rugby league players. A periodized field, strength, and power training program was implemented, with TLs progressively increased in the general preparatory phase of the season and reduced during the competitive phase of the season. TLs and injuries were recorded for each training session. Overall, TL was significantly related ($P < 0.05$) to overall injury ($r = 0.82$), non-contact field injury ($r = 0.82$), and contact field injury ($r = 0.80$) rates. Significant relationships were also observed between the field TL and overall field injury ($r = 0.68$), non-contact field injury ($r = 0.65$), and contact field injury ($r = 0.63$) rates. Strength and power TLs were significantly related to the incidence of strength and power injuries ($r = 0.63$). There was no significant relationship between field TLs and the incidence of strength and power injuries. However, strength and power TLs were significantly ($P < 0.01$) associated with the incidence of contact ($r = 0.75$) and non-contact ($r = 0.82$) field training injuries. These findings suggest that the harder rugby league players train, the more injuries they will sustain, and that high strength and power TLs may contribute indirectly to field injuries. The major takeaway from this study revolves around monitoring TLs and carefully scheduling field and resistance training sessions in order to avoid residual fatigue which may result in training-related injuries.

2.2.5 American Football Training Load Monitoring

Flatt et al. (2018)

The purpose of this study was to determine whether recovery of cardiac-autonomic activity to baseline occurs between consecutive-day training sessions among positional groups of a collegiate football team during spring training camp. A secondary aim was to evaluate relationships between 4-week HRV and TL parameters. Baseline HRV was compared with HRV approximately 20 hours after each training session among positional groups composed of skill (n = 11), mid-skill (n = 9), and linemen (n = 5). The importance of this study was that through TL monitoring, the authors were able to confidently conclude that ∼20-hour recovery time between training sessions on consecutive days may not be adequate for restoration of cardiac-parasympathetic activity to baseline among linemen. Additional conclusions drawn suggested that a capacity for greater chronic TLs may be protective against perturbations in cardiac-autonomic homeostasis among American college football players. Due to the increase demands and competitiveness of sport, these are valuable findings which may help better prepare athletes for competition and protect them from preventable injuries.

Ward et al. (2018)

The aim of this study was to identify the relationship between inertial sensor TL metrics and non-contact injury in NFL athletes. Additionally, this study was the first to evaluate the relationship between TL variables and non-contact injury in an NFL population across a single season. TL was evaluated using 11 inertial sensor metrics that were defined according to three sub-categories: (1) TL variables; (2) IMA variables; and, (3) Impact variables. Of the five joint models, the model consisting of TL, TLLow, and ImpactsHigh had the strongest relationship with non-contact soft tissue injury. Overall, these findings suggest that a combination of inertial sensor variables may be useful in describing injury risk within the sport of American football. Additionally, this is study provides another example of the benefits of TL monitoring over the course of a season and how results can be interpreted to better protect athletes from preventable injuries.

2.2.6 Soccer Training Load Monitoring

Gentles et al. (2018)

The purpose of this study was to use GPS, accelerometers, and sRPE to examine the demands of a Division II women's soccer team. ZephyrTM BioHarnesses were used to collect tri-axial acceleration information and GPS derived variables for all matches and practices. Acceleration data was used to calculate TL, which in this instance was a measure of mechanical load that includes only locomotor related accelerations. GPS was used to quantify total distance and distance in five speed zones. Mean TL, total distance, and sRPE during match play was 20,120 ± 8609 N·s, 5.48 ± 2.35 km, and 892.50 ± 358.50, respectively. Mean TL, total distance, and sRPE during practice was 12,410 ± 4067 N·s, 2.95 ± 0.95 km, and 143.30 ± 123.50, respectively. Additionally, several very large to nearly perfect correlations were found between TL and total distance ($r = 0.95$; $p < 0.001$), TL and sRPE ($r = 0.84$; $p < 0.001$), and total distance and sRPE ($r = 0.82$; $p < 0.001$). This study detailed the mechanical demands of Division II women's soccer match play and demonstrated that TL is a good indicator of total distance which is often a primary indicator of fatigue and injury risk. Furthermore, these findings can be applied to specific phases of a competitive season in order to both, assess phases which produce higher fatigue across teams, positions, and individuals and better prepare athletes for that expected fatigue.

Jeong et al. (2011)

The aim of this study was to quantify the physiological loads of programmed “pre-season” and “in-season” training in professional soccer players. TLs were calculated by multiplying sRPE by the duration of training sessions. Each session was sub-categorized as physical, technical/tactical, physical and technical/tactical training. Average physiological loads in pre-season were significantly higher compared with in-season and there was a greater proportion of time spent in 80–100% maximum HR zones. Such differences appear attributable to the higher intensities in technical/tactical sessions during pre-season. These findings demonstrate that pre-season training is more intense than in-season training and also provide guidance into examining TL fluctuations across a competitive season.

Malone et al. (2015)

The purpose of this study was to quantify the seasonal TL completed by professional soccer players of the English Premier League. Although daily TL did not differ during each week of the preseason phase, total distance covered was 1304 (95% CI 434–2174) m greater in the 1st mesocycle than in the 6th. Additionally, %HRmax values were greater (3.3%, 1.3−5.4%) in the 3rd mesocycle than in the first. Furthermore, TL was lower on the day before match (MD-1) than 2 (MD-2) to 5 (MD-5) days before a match, although no difference was apparent between these latter time points. Like many of the aforementioned studies, these findings suggest that TL monitoring is a valuable tool for understanding the characteristics of specific phases within a season.

Oliveira et al. (2019)

The authors of this study provided a multimodal approach for assessing internal and ETLs in a professional European soccer team. The aim of this study was to quantify internal and ETL within five microcycles. GPS was used to measure the total distance covered and distances of different exercise training zones. sRPE scores and the amount of CK created during daily training sessions for the 2015–2016 in-season period were also measured. The main results indicated that there was a significant difference in training intensity for zone 1 between M2 and M4 (4010.2 ± 103.5 and 4507.6 ± 133.0 m, respectively); a significant difference in training intensity for zone 3 between M1 and M5 (686.1 ± 42.8 and 801.2 ± 61.2 m, respectively); a significant difference in the duration of the training sessions and matches between M2 and M5 (69.2 ± 2.1 and 79.6 ± 2.3) and M3 and M5 (69.7 ± 1.0 and 79.6 ± 2.3); and finally, there was a significant difference in CK between M3 and M2 (325.5 ± 155.0 and 194.4 ± 48.9). This study provided the first report of daily external and ITLs and weekly accumulated load (training sessions and match demands) during one, two, and three-game week schedules in a group of elite soccer players. Significant differences were also found in daily and accumulated loads for within- and between-game schedules.

Scott et al. (2013)

The purpose of this study was to compare various measures of TL derived from physiological (HR), perceptual (sRPE), and physical (GPS and accelerometer) data during in-season field-based training for professional soccer. While the volume of HSR and VHSR provided significant relationships with ITL, physical-performance measures of TD, low-speed activity (LSA) volume, and total TL appear to be more acceptable indicators of ETL, due to the greater magnitude of their correlations with measures of ITL. These findings provide valuable information regarding the characteristics on ITL, ETL, and total TL.

Strauss et al. (2018)

A primary aim of this study was to assess the ITL and ETL demands of sub-elite female soccer players within and between matches during a tournament. Selected groups of university-level female soccer players were recruited to complete the physical assessments within a two-week period either before or after a tournament. Within match comparisons showed that player load decreased significantly ($p \leq 0.05$) in the second half (ES: 0.4). Relative distance, LIA and HIA also decreased in the second half with possibly trivial to likely small changes. The biggest magnitude of change was seen with a large decrease (ES: -1.2) in relative distance covered between Match 2 and 5. Evidence suggests that accumulated fatigue throughout a multi-day tournament would affect performance negatively. As competition becomes more congested throughout a competitive season, these findings are crucial for understanding which aspects of athlete performance are most affected. Additionally, these findings are exceptionally useful due to the fact that post-season championship competitions are usually conducted in a tournament-style of play. Furthermore, these competitions are generally more demanding, have lower margins of error, and have greater implications on overall team success.

Esco et al. (2014)

This study was conducted to determine if the Polar FT40 could accurately track changes in VO2max in a group of female soccer players. However, the Polar FT40 did not appear to be a valid method for predicting changes in individual VO2max following eight weeks of endurance training in female collegiate soccer players. As the world becomes more reliable on technology to guide decision-making, this study has immeasurable value. In addition to regularly monitoring TLs throughout a season, there may be a need to conduct lab-based or more formal VO2max assessments in order to better gauge athlete’s fitness throughout a training program, phase of a season, or a competitive season collectively.

Rebelo et al. (2012)

The aim of the present study was to evaluate the relationship between a new method to monitor TL in soccer (VAS-TL), and two established HR-based methods (TRIMP and Edwards' method). The authors found significant correlations ($r = 0.60\text{–}0.72$; $p < 0.05$) between VAS-TL, TRIMP, and the Edwards' TL method, with the highest correlations achieved in matches. The authors suggested that VAS-TL was easy to apply and was sensitive to differences in positional role and physical capacity. Thus, this applied method may be used in addition to the usual TL methods, allowing for daily quantification of individual TL in soccer.

Bradley et al. (2013)

The aim of this study was to compare the match performance and physical capacity of players in the top three competitive standards of English soccer. The data demonstrate that high-intensity running distance was greater in players at lower compared to higher competitive standards despite a similar physical capacity in a subsample of players in each standard. These findings could be associated with technical characteristics inherent to lower standards that require players to tax their physical capacity to a greater extent but additional research is still required to confirm these findings.

Ehrmann et al. (2016)

The aim of this study was to investigate the relationship between GPS variables measured in training and gameplay and injury occurrences in professional soccer. 19 professional soccer players competing in the Australian Hyundai A-League were monitored for 1 entire season using 5 Hz GPS units (SPI-Pro GPSports) in training sessions and pre-season games. The measurements obtained were total distance, high-intensity running distance, very–high-intensity running distance, new body load, and meters per minute. Overall, it was concluded that periods of relative under-preparedness could potentially leave players unable to cope with intense bouts of high-intensity efforts during competitive matches. Although limited by Fédération Internationale de Football Association regulations, the results of this study isolated 2 primary contributors (under preparation and acute increases in exercises intensity) to soft tissue injuries for coaches and sports scientists to consider when planning and monitoring training. This study provides evidence of the effectiveness of TL monitoring for predicting and preventing injuries throughout a competitive season. Furthermore, these findings can be utilized to provide approaches for preparing athletes for the demands of competition while avoiding injury, undertraining, and overtraining.

Flatt et al. (2015)

This study evaluated the 7-day mean and coefficient of variation (CV) of supine and standing ultrashort log-transformed root mean square of successive R-R intervals multiplied by 20 (lnRMSSDx20) obtained with a smartphone application (app) in response to varying weekly TL. In addition, the authors aimed to determine if these values could be accurately assessed in as few as 5 or 3 d/wk periods. The 5- and 3-d measures within each week provided very good to nearly perfect intra-class correlations (ICCs .74–.99) with typical errors ranging from 0.64 to 5.65 when compared with the 7-d criteria. Overall, this study supports the use of the mean and CV of lnRMSSD measured across at least 5 d for reflecting weekly values. The supine lnRMssDx20 CV as measured across 7, 5, and 3 d was the most sensitive marker to the changes in TL in the 3-wk period. In conclusion, this study not only highlights the effectiveness of measuring fluctuations in resting HR in response to varying weekly TLs, but also provides support for monitoring these fluctuations over shorter periods if need be. This can help influence decision-making and also be of use during times of highly congested competition schedules (two, three, or four games per week in addition to practices and lifting sessions) or for new athletes on the team who have no available baseline HR data to reference.

Huggins et al. (2020)

The aim of this study was to examine the influence of days rest and increases in TL between matches on injury rate (IR), relative risk (RR), and odds of injury. Assessment of risk factors; days between matches, daily exposures, TL, and injury data were tracked daily in men (n =) and women (n =) NCAA DI soccer players. Overall, acute non-contact (NC) and NC-overuse IRs expressed per 1000 athlete exposures (AEs), RR and odds ratios (OR) were determined. Match IR (per 1000AEs [95% CI]) was 47.9 [39.1, 56.6] in men and 39.0 [31.1, 46.9] in women. Odds of being injured in a match with 1–5 vs. 6+ days rest was increased in men (OR [95% CI] 1.93 [1.15, 3.23] (p=0.01) and women (1.79 [1.02, 3.17] p=0.04). Pre-season injury rates were 2.11 and 1.68 times higher than the seasonal average rates for men (26.8/1000 AE vs. 12.7/1000 AE) and women (28.8/1000 AE vs. 17.1/1000 AE). In women, acute NC IR in matches with 1–3 vs. 4+ days' rest were elevated (RR=3.01 [1.11, 8.14] p=0.03). NC-overuse IR in women during matches were elevated for both 1–3 vs. 4+ and 1–5 vs. 6+ days rest (RR=2.24 [1.03, 4.88) p=0.05; 7.85 [1.06, 57.94] p=0.04). No differences in RRs exit between matches for starters in both men and women. In men, for each additional 3500m covered on a session and each additional 60 min of training, odds of NC-overuse injury increased 1.70 [1.38, 2.10] and 1.83 [1.59, 2.12]. In women, for each additional 3000m covered on a given session, odds of overall injury increased 1.41 [1.24, 1.60] and for each additional 45 min played acute NC odds increased 1.51 [1.12, 2.03]. These findings suggest the current structure and TL may be putting players at increased risk for injury. Additionally, these findings can be used to guide the NCAA in determining optimal scheduling and recovery for injury prevention.

2.2.7 Summary of Monitoring Training Load across Different Sports

Research has shown that the previously mentioned TL monitoring methods within this literature review can be applied across a wide range of sports. In fact, these methods have been validated in sports such as basketball, volleyball, wrestling, rugby, American football, and soccer populations competing at all levels (i.e. amateur, semi-professional, professional) (Bradley et al. 2013; Esco et al. 2014; Ehrmann et al. 2016; Elloumi 2012; Flatt et al. 2015; Flatt et al. 2018; Gabbett 2011; Gentles et al. 2018; Heishman et al. 2018; Heishman et al. 2020; Huggins et al. 2020; Hugjiltu 1999; Jeong et al. 2011; Malone et al. 2015; Manzi et al. 2010; Oliveira et al. 2019; Paulauskas et al. 2019; Rebelo et al. 2012; Roth 2019; Scott et al. 2013; Sprague 2014; Strauss et al. 2018; Ward et al. 2018). Across sports, there are several similarities regarding the implementation of TL monitoring methods and interpretation of the results. Generally, TL monitoring is conducted actively, but retroactive analysis have also been conducted. However, both methods provide significant evidence regarding the relationships between ITL, ETL, and fatigue, performance, and recovery. Similarities also exist between monitoring periods across sports. The most common phases of a season to monitor TLs appear to be; during the pre-season, in-season, and post-season competitive phases. Overall, significant changes in TLs (Malone et al. 2015; Strauss et al. 2018; , distance covered, practice intensity (Heishman et al. 2020; Jeong et al. 2011), match-congestion, movement patterns (Sprague 2014), hormonal responses(Roth 2019; Hugjiltu 1999; Oliveira et al. 2019), TS and TSF (Elloumi 2012), non-contact and contact injury rates (Gabbett 2011, Gentles et al. 2018; Huggins et al. 2020; Ward et al. 2018 recovery time (Flatt et al. 2018) were typically reported, regardless of sport.

Although there is currently limited research quantifying training or competition TL outside of time motion analysis in basketball (Edwards et al. 2018), researchers have been able to adapt successful TL monitoring concepts from other sports and apply it within their setting (Conte et al. 2018; Heishman et al. 2018; Heishman et al. 2020; Manzi et al. 2010; Paulauskas et al. 2019). Primary methods for assessing TL within this population are; sRPE, HR-based TL monitoring, CMJ, stratification of athletes by ability, playing time, FT:CT, RSIMod, and IMA. During periods of high-intensity training and/or periods where athletes have a limited time to recover before the next competition, fatigue presents itself several ways. Previous research within the collegiate basketball population has suggested that acute increases in TLs results in increased peripheral fatigue which then leads to decreased power production and CMJ height (Heishman et al. 2018). Additionally, moderate perturbations in FT:CT and RSIMod paralleled the weeks with intensified training (Heishman et al. 2020). Simply put, athlete's reaction times are also negatively affected during periods of intense training. Due to the demands of the sport and highly competitive periods, fluctuations in TL have also been closely monitored in elite basketball populations as well (Conte et al. 2018; Paulauskas et al. 2019;). In general, significant differences in TL were observed with the highest TL, monotony, and strain appearing later in the season (Paulauskas et al. 2019). Additionally, significant TL spikes up to 226% and 220% were observed on a weekly basis throughout a collegiate basketball season (Conte et al. 2018).

Within the volleyball population, research is limited regarding TL monitoring but the FMS™ has been used to assess the impact fluctuations in TL has over the course of a competitive season (Sprague 2014). Similar to other populations, it was observed that increased acute and cumulative fatigue negatively affects the peripheral nervous system and presents itself by diminishing movement patterns. These diminished movement patterns can later result in decreased power, strength, and other performance measures.

Within the collegiate wrestling population, hormonal analysis are commonly utilized in order to monitor TLs (Hugjiltu 1999 and Roth 2019). Although more invasive, these methods provide insight regarding biological markers of muscle damage and inflammation which usually coincide with subjective measures of muscle fatigue and sleep quality. Research reported that self-reported levels of muscle soreness and fatigue were significantly higher from pre-season through mid-season, but leveled off late into the season. Additionally, CK followed a similar pattern early into the season compared with pre-season and decreased at the end of season. Plasma TNF-α and IL-8 levels increased modestly late into season compared with pre-season.

Lastly, relationships between exercise, testosterone, and cortisol were reported while relationships between non-exercise, PRL, and LH were also reported.

Within contact sports, a multitude of TL monitoring methods have been successfully implemented. Rugby for instance has successfully implemented a wide range of methods, (i.e. questionnaires, physiological monitoring approaches, etc.), each of them possessing the capacity to accurately detect significant changes in TS, TSF, and injury types (Elloumi 2012 and Gabbett 2011). The changes in TL, TS and TSF correlated significantly over the training period (r=0.63-0.83). These findings provide evidence of the effectiveness of a multi-faceted approach for monitoring TL fluctuations over specific phases of competition preparation (Elloumi 2012). Additionally, TL was significantly related ($p < 0.05$) to overall injury ($r = 0.82$), non-contact field injury ($r = 0.82$), and contact field injury ($r = 0.80$) rates. For football, TL monitoring has been conducted by measuring recovery of cardiac-autonomic activity (Flatt et al. 2018), relationships between 4-week HRV and TL parameters (Flatt et al. 2018), and inertial sensor TL metrics and non-contact injury (Ward et al. 2018).

Overall, research regarding TL monitoring in soccer is well-supported, well-reported, and well-explored. Comparatively, this mainly applies to male soccer athletes and their respective teams and organizations. Nonetheless, TL monitoring in soccer ranges from non-invasive techniques such as sRPE and questionnaires to more invasive techniques like HR-based TL monitoring (Bradley et al. 2013; Ehrmann et al. 2016; Esco et al. 2014; Flatt et al. 2015; Gentles et al. 2018; Huggins et al. 2020; Jeong et al. 2011; Malone et al. 2015; Rebelo et al. 2012; Scott et al. 2013; Strauss et al. 2018) lactate threshold, and hormonal analysis (Oliveira et al. 2019). Within the sport of soccer, previous research has shown that significant and nearly perfect relationships between ITL (HR zone duration) and ETL (total distance), and total distance and sRPE exist during match play ($p < 0.05$) (Gentles et al. 2018; Scott et al. 2013; Strauss et al. 2018; Rebelo et al. 2012; Ehrmann et al. 2016). Significant differences in TLs have also been reported between periods of high-stress (i.e. more frequent and intense practices or games) versus periods of lower stress ($p < 0.05$) (Jeong et al. 2011; Malone et al. 2015; Oliveira et al. 2019). Furthermore, research has also identified significant relationships between sudden fluctuations or "spikes" in TL, lower HRV, and elevated acute and overuse non-contact injury rates ($p = 0.01$ – 0.04) (Flatt et al. 2015; Huggins et al. 2020).

2.3 Positional/Game Demands of Soccer

Alexander et al. (2014)

Understanding the overall and position-specific demands of soccer are integral for accurately interpreting TL fluctuations over the course of a competitive season. Although HR monitoring and motion analysis has become commonplace in most professional environments, the literature on amateur soccer is quite scarce and warrants more attention. The purpose of this study was to explore the physical and technical demands of the women's college soccer game through a case study approach. 11 female collegiate soccer players from a single NCAA institution were tracked with GPS devices during a competitive season. Physical variables and technical variables were analyzed to gain further insight into the specific events that occur during a women's college soccer match. The authors reported that significant differences existed between positions for total distance covered during a match, with the forward and central defensive midfielder position covering the greatest distance during a match on average. The central defender position covered a significantly less amount of distance during a match than the other five positional subcategories. Outside players (forward, outside midfielder, and fullback) covered the greatest distance at high-speed velocity bands and perform the highest volume of high-speed efforts. The only significantly different technical variable found was the pass completion percentage of the central defensive midfielder compared with other positions. Therefore, the current investigation highlights the unique characteristics of female collegiate soccer players when separated and analyzed by the positional subcategories. With uniqueness present in a once thought to be homogenous population, the demand for individualized training protocols becomes paramount to increase chances of optimal performance while simultaneously decreasing risk of injury.

Martínez-Lagunas et al. (2014)

This article aimed to provide an overview of a series of studies that had been published on the specific characteristics of female football players and the demands of match-play. Mean values reported in the literature for age (12–27 years), body height (155–174 cm), body mass (48–72 kg), percent body fat (13%–29%), VO2max (45.1–55.5 mL/kg/min), Yo-Yo Intermittent Recovery Test Level 1 (780–1379 m), maximum HR (189–202 bpm), 30-m sprint times (4.34–4.96 s), and counter-movement jump or vertical jump (28–50 cm) varied mostly according to the players' competitive level and positional role. Reported mean values for total distance covered (4–13 km), distance covered at high-speed (0.2–1.7 km), average/peak HR (74%–87%/94%–99% HRmax), average VO2max (52%–77%/96%–98% VO2max), and blood lactate (2.2–7.3 mmol/L) during women's football match-play vary according to the players' competitive level and positional role. Additionally, the authors included special considerations that coaches and other practitioners should be aware of when working with female athletes such as the menstrual cycle, potential pregnancy and lactation, common injury risks (particularly knee and head injuries) and health concerns (e.g., female athlete triad, iron deficiency, and anemia) that may affect players' football performance, health or return to play. This study further supports the development and implementation of TL monitoring tools in order to develop individualized training protocols for optimizing performance and reducing injuries.

Oliveira et al. (2019)

Often times, highly competitive soccer teams participate in one, two- or three-games per week. Additionally, athletes on those teams also participate in required practices, weightlifting sessions, and amateur athletes also have to complete academic coursework. Therefore, it is necessary to ensure optimal match-day performance and full recovery. The aim of this study was to quantify internal and ETL within five microcycles: M1 and M2 – one-game weeks; M3 and M4 – two-game weeks; M5 – three-game week. 13 elite soccer players participated in this study. A GPS was used to measure the total distance covered and distances of different exercise training zones (1–5) and s-RPE scores and the amount of CK created during daily training sessions for the 2015–2016 in-season period were measured to further quantify TL. The data were analysed with respect to the number of days prior to a given match. The main results indicated that there was a significant difference in training intensity for zone 1 between M2 and M4 (4010.2 ± 103.5 and 4507.6 ± 133.0 m, respectively); a significant difference in training intensity for zone 3 between M1 and M5 (686.1 ± 42.8 and 801.2 ± 61.2 m, respectively); a significant difference in the duration of the training sessions and matches between M2 and M5 (69.2 ± 2.1 and 79.6 ± 2.3) and M3 and M5 (69.7 ± 1.0 and 79.6 ± 2.3); and finally, there was a significant difference in CK between M3 and M2 (325.5 ± 155.0 and 194.4 ± 48.9). Moreover, there was a significant decrease in TL in the last day prior to a match, for all microcycles and all variables. There was no significant difference with respect to s-RPE. Thus, the authors reported that this study provided the first report of daily external and ITLs and weekly accumulated load (training sessions and match demands) during one, two, and three-game week schedules in a group of elite soccer players. Expected significant differences were found in daily and accumulated loads for within- and between-game schedules. A similar pattern was exhibited for one- and two-game week microcycles regarding the day before the match, which exhibits a decrease in all variables. Despite the different number of games played per week, TL remained similar between microcycles for zone 2 and 5, plus s-RPE. In support of the aims of this dissertation, this study provides evidence of the fluctuation in TLs based on the amount of competitions within a calendar week. Furthermore, this study has highlighted a gap in current research concerning TL fluctuations over the course of a competitive season which may be composed of several one-, two-, and three-game weeks. Although, it may be of interest to further investigate how TLs fluctuate by position during these microcycles.

Sausaman et al. (2019)

The authors of this study reiterated the common theme concerning women's collegiate soccer. The research is scarce which has left gaps in the literature with little information available detailing the physical demands at different standards of play. The purpose of this study was to elucidate the physical demands of the NCAA DI collegiate level and identify differences between playing positions. 23 field players were observed during four competitive seasons using 10-Hz GPS units (Catapult Sports, Melbourne, Australia). Descriptive statistics and 95% confidence intervals were used to determine group and position-specific physical demands. Linear mixed modelling (LMM) was used to compare attacker, midfielder, and defender position groups. Total distance, high-speed distance, and sprint distance were 9486 ± 300 m, 1014 ± 118 m, and 428 ± 70 m, respectively. Furthermore, attackers were observed to cover the greatest distance at all speeds compared to midfielders and defenders. The authors findings suggest that the physical demands of NCAA DI women's soccer differ by position, but overall appear lower compared to higher standards of play. Therefore, coaches and sports scientists responsible for the physical training of NCAA DI collegiate players should consider the specific physical demands of the collegiate level and playing position when prescribing training, as well as in the development of their annual training programs. Although this study contributed to filling gaps within the literature regarding the physical demands of NCAA DI women's collegiate soccer, it created another gap as the physical demands of goalkeepers were not evaluated. In an effort to improve overall team performance and reduce injuries, this study further emphasizes the importance of a focused approach for detailing the physical demands of NCAA DI women's collegiate soccer overall, by position, and over the course of several phases throughout a competitive season.

Andrzejewski et al. (2016)

The aim of the present study is to examine how various playing positions and end result (i.e. won, drawn or lost match) affect the total covered distance and distances covered at low and high-intensity by German Bundesliga soccer players. Match performance data were collected from 350 soccer players competing in the German Bundesliga during the 2014/2015 domestic season. A total of 4393 individual match observations were undertaken on outfield players. The analysis was carried out using the Impire AG motion analysis system recording all movements of players in all 306 matches. The examined variables included total distance covered and distance covered in low-intensity and high-intensity running. The analysis of distance covered at high intensity shows that central defenders and full-backs covered shorter distances in won matches than in lost matches ($p \leq 0.01$). Furthermore, forwards covered significantly longer distances in won matches than in drawn and lost matches ($p \leq 0.05$). In conclusion, the results indicate the importance of considering match outcome and playing positions in the assessment of physical aspects of soccer players' performance. Additionally, these findings can be further advanced through TL monitoring methods in order to characterize certain phases of a competitive season which may be less competitive (exhibition and non-conference play) or when games may be more valuable (conference and championship play) by position.

Bangsbo et al. (2014)

Bangsbo et al. (2014) profiled the demands on a soccer player during a game which were determined from match analysis and physiological measurements during match play. Several conclusions were drawn which included factors that most influence the demands of a player and important physical and energy system characteristics. The authors stated that, "a myriad of factors influences the demands of a player, such as the player's physical capacity, technical qualities, playing position, tactical role and style of playing, as well as ball possession of the team, quality of the opponent, importance of the game, seasonal period, playing surface and environmental factors". It was also reported that high-intensity exercise periods are important since the amount of high-speed running has been shown to be a distinguishing factor between top-class players and those at a lower level. Additionally, fitness is a primary component of success with being that the aerobic energy system is highly taxed during a soccer game, with average and peak HRs around 85% and 98% of maximal values, respectively, corresponding to average oxygen uptake of around 70% of maximum. Furthermore, the many intense actions (>100) during a game indicate that the rate of anaerobic energy turnover is also high during game periods, with a significant rate of utilization of creatine phosphate and lactate accumulation. Therefore, the authors concluded that careful planning of training and nutritional strategies are required in preparation for training and games. Although research has reported differences in player demands across positions, it may be beneficial to further investigate these differences across a competitive season.

Bradley et al. (2014)

The aim of this study was to examine gender differences in match performance characteristics of elite soccer players. 54 male and 59 female soccer players were tracked during UEFA Champions League matches using a multi-camera system. Male players covered more ($P < .01$) distance than female players in total during a match (Effect Size [ES]: 0.5) and at higher speed thresholds (>15, >18, 18–21, 21–23, 23–25 and >27 km h^{-1}; ES: 0.7–1.4). These findings are important and highlight the differences between sexes, game-play, and physical demands placed on the male and female soccer player during competition. Additionally, these findings provide evidence that exercise recommendations and TL monitoring approaches should be individualized based on sex, position-group, and game demands.

Clarke et al. (2018)

The purpose of this study was to compare positional differences in the physical and technical demands of Australian Football League Women's (AFLW) match-play. A secondary aim was to examine the time course changes in activity profiles during AFLW match-play. Absolute measures of running performance did not differ between position groups. Relative total distance was moderately greater (ES = ∼0.80, $p < 0.05$) for midfielders, small backs and small forwards (125–128 m min−1) than tall backs and tall forwards (102–107 m min−1). Relative HSR distance was greater (ES = ∼0.73) for midfielders and small backs (∼28 m min−1) than tall backs (17 m min−1). Analysis of technical performance indicators showed: midfielders and small forwards had the most inside 50s; tall backs had the highest number of rebound 50s; tall forwards scored more goals; while midfielders made more tackles ($p < 0.05$). Comparatively, all relative running performance measures were reduced in the fourth quarter when compared to the first and second quarters (ES = 0.32–0.77). When applied, these data can be used as benchmarks for analysis of AFLW match demands and assist in developing specific training strategies. Altogether, this study effectively profiled the physical and technical demands of elite women's soccer match-play. However, a gap still remains regarding the physical and technical demands of goalkeepers and fluctuations in TLs for all position groups across a competitive season.

Datson et al. (2017)

The purpose of this study was to provide a detailed analysis of the physical demands of competitive international female soccer match play. A total of 148 individual match observations were undertaken on 107 outfield players competing in competitive international matches across two seasons using a computerized tracking system (Prozone Sports Ltd., Leeds, England). The authors reported that total distance and total high-speed running distances were influenced by playing position, with central midfielders completing the highest (10,985 ± 706 m and 2,882 ±

500 m) and central defenders the lowest (9,489 ± 562 m and 1,901 ± 268 m) distances, respectively. Greater total very high-speed running distances were completed when a team was without (399 ± 143 m) compared to with (313 ± 210 m) possession of the ball. Most sprints were over short distances with 76% and 95% being less than 5 and 10 m, respectively. Between half reductions in physical performance were present for all variables, independent of playing position. Overall, this study provides novel findings regarding the physical demands of different playing positions in competitive international female match play and provides important insights for physical coaches preparing elite female players for competition. Furthermore, it highlights the need for similar monitoring approaches within less-competitive levels of women's soccer across specific phases of a competitive season in order to identify the demands of each position, when physical demands and TLs are the highest or lowest, and where reductions in physical performance are present.

Jagim et al. (2020)

The authors of this study also stated that research describing the match and specific positional demands during match play in women's collegiate soccer is limited. Therefore, the purpose of the study was to quantify the match demands of NCAA DIII soccer and assess position differences in movement kinematics, HR, and energy expenditure. 25 NCAA DIII women soccer players (height: 1.61 ± 0.3 m; body mass: 66.7 ± 7.5 kg; fat-free mass: 50.3 ± 6.5 kg; body fat%: 25.6 ± 5.1%) were equipped with a wearable GPS to assess the demands of 22 matches throughout a season. Players were categorized by position (goal keepers (GK), center defenders (CD), flank players (FP), forwards (F), and center midfielders (CM)). Players covered 9807 ± 2588 m and 1019 ± 552 m at high speeds (>249.6 m·m−1), with an overall average speed of 62.85 ± 14.7 m·m−1. This resulted in a mean HR of 74.2 ± 6% HR max and energy expenditure of 1259 ± 309 kcal. Significant and meaningful differences in movement kinematics were observed across position groups. CM covered the most distance resulting in the highest TL.

FP covered the most distance at high speeds and mean HR values were highest in CM, CB, and FP positions. These findings not only emphasize and profile the differences in position-specific physical demands and TLs during match play, but also suggest that these differences may be worthwhile to further explore across specific phases of a competitive season.

Krustrup et al. (2005)

The purpose of this study was to examine the activity profile and TL of elite female soccer players during match play and to study the relationship between training status and physical match performance. Time-motion analysis and HR recordings were performed on 14 elite female soccer players during competitive matches. In addition, the players carried out a laboratory treadmill test and the Yo-Yo intermittent recovery test. The total distance covered during a game was 10.3 km (range: 9.7–11.3) with high-intensity running (HIR) accounting for 1.31 km (0.71–1.70). HIR was performed 125 times (72–159) for 2.3 s (2.0–2.4) on average. The average and peak HR in a game were 167 bpm (152–186) and 186 (171–205), respectively, corresponding to 87% (81–93) and 97% (96–100) of HRmax. VO2max was 49.4 mL·min1 ·kg1 (43.4–56.8), and incremental treadmill test (ITT) performance was 4.49 min (3.38–5.17). The Yo-Yo test performance was 1379 m (600–1960). Although, total distance covered during match play did not correlate with VO2max or ITT performance, it did correlate with the Yo-Yo test result (r 0.56, P 0.05). Significant positive correlations were observed between HIR and VO2max (r 0.81, P 0.05), ITT (r 0.82, P 0.05), and Yo-Yo test performance (r 0.76, P 0.05). No relationship was observed between %HRmax during match play and any of the performance measures. To conclude, the present study demonstrated that 1) HIR during games varies markedly between elite female soccer players, 2) all players have high HR throughout a competitive game with periods of near-maximal values, 3) the distance covered by HIR during match play is closely related to the physical capacity, and 4) the Yo-Yo intermittent recovery test can be used as an indicator of the physical match performance of elite female players. In accordance with the aforementioned study findings, this study specifies the importance of monitoring physical demands and TL, specifically HIR, between position-groups throughout a competitive game and over the course of a season.

Lockie et al. (2018)

Playing positions in soccer can exhibit different movement demands during a match, contributing to variations in physical and performance characteristics. Additionally, NCAA soccer features different substitution rules when compared to FIFA-sanctioned matches, which could influence each players' characteristics. Therefore, this study aimed to determine the athletic performance characteristics of NCAA Division I female soccer players. 26 players (3 goalkeepers; 8 defenders; 10 midfielders; 5 forwards) from the same squad completed assessments of: lower-body power (vertical and standing broad jump); linear (0–5, 0–10, 0–30 meter [m] sprint intervals) and change-of-direction (pro-agility shuttle; arrowhead change-of-direction speed test) speed; and soccer-specific fitness (Yo-Yo Intermittent Recovery Test [YYIRT] levels 1 and 2). Players were split into position groups, and a Kruskal–Wallis H test with post hoc pairwise analyses ($p \leq 0.05$) calculated significant between-group differences. There were no differences in age, height, or body mass between the positions. Midfielders had a faster 0–5 m time compared with the defenders ($p = 0.017$) and the goalkeepers ($p = 0.030$). The defenders ($p = 0.011$) and midfielders ($p = 0.013$) covered a greater YYIRT2 distance compared with the goalkeepers. There were no other significant between-position differences. Overall, the authors reported that NCAA Division I collegiate female players from the same squad demonstrated similar characteristics as measured by soccer-specific performance tests, which could allow for flexibility in position assignments. Additionally, a relatively homogenous squad could also indicate commonality in training prescription, particularly regarding acceleration and high-intensity running. However, as previous research has elucidated that in-game physical demands differ between specific positions, monitoring and profiling these characteristics throughout specific phases of a competitive season may contribute novel findings to the current literature.

Silva et al. (2015)

The purpose of the first part of this project was to compare and contrast HR monitoring and session RPE as tools to assess ITL, specifically in soccer players. While both tools have their limitations, it was reported that each method served as a valuable tool to assess the ITL of a player. The purpose of the second portion of this project was to present a case study to design, execute and evaluate the use of HR monitors as a tool for periodization in a NCAA DI Men's Soccer team across a competitive season. The periodization schedule was created and based upon ITL information gathered from HR monitors and anchored to known periodization goals as well as coach and team-specific goals. Upon analyzing the data it was shown that, throughout the season, scheduled TLs deviated slightly from the periodization schedule but, in large part, were adhered to and tended to yield the desired effect of sustained maintenance of fitness levels. In turn, this seems to have impacted the team 'on-the-pitch' as the team went on to have one of the most successful seasons in recent program history. Lessons learned from this case-study analysis should serve to strengthen the coaching staff's knowledge regarding HR monitoring and how to best utilize this method in creating an optimal periodization schedule. As previous literature and this case study suggest, the knowledge of ITL can be a useful tool to a coach or trainer seeking to optimize a team or player's potential. Altogether, when TL is accurately monitored (whether it be via sRPE or HR monitors) more suitable approaches for maintaining and improving fitness levels and performance can be suggested for implementation. Additionally, it may be beneficial to examine the common physical demands and TLs associated for teams and specific position groups in order to further periodization goals and outcomes.

2.3.1 Summary of Positional/Game Demands of Soccer

Although evidence exists which supports our current understanding of how ITL and ETL can be influenced within the sport of soccer, it is important to acknowledge the demands of the sport itself and how each position differs within this construct. Generally, research suggests that there are overarching demands which all athletes should be able to withstand (Alexander et al. 2014; Andrzejewski et al. 2016; Bangsbo et al. 2014; Bradley et al. 2014; Clarke et al. 2018; Datson et al. 2017; Jagim et al. 2020; Krustrup et al. 2005; Lockie et al. 2018; Martínez-Lagunas et al. 2014; Oliveira et al. 2019; Sausaman et al. 2019; Silva et al. 2015). These demands include running distances and speeds at differing intensities and achieving or maintaining average and maximal HRs.

Additionally, in order to perform at high-levels research suggests that athletes should possess adequate levels of lower-body power, linear and change of direction speed, and soccer-specific fitness (Lockie et al. 2018). Although somewhat different but still related, soccer athletes should typically also meet characteristics within each competitive level classification. Generally, these characteristics are age, height, and weight. Although they are not primary determinants of success on the pitch, they can be used as a surrogate measure to identify those most likely to succeed (Lockie et al. 2018).

However, when examined closer the demands of soccer differ significantly by position during competition ($p < 0.05$) (Alexander et al. 2014; Andrzejewski et al. 2016; Clarke et al. 2018; Datson et al. 2017; Jagim et al. 2020; Lockie et al. 2018; Sausaman et al. 2019). For instance, Alexander et al. (2014) reported that significant differences ($p < 0.05$) existed between positions for total distance covered during a match, with the forward and central defensive midfielder position covering the greatest distance on average. However, the central defender position covered a significantly less amount of distance during a match than all other positional subcategories aside from goalkeepers which had the lowest values in all ETL measures. Additionally, outside players (forward, outside midfielder, and fullback) covered the greatest distance at high-speed velocity bands and perform the highest volume of high-speed efforts. Similar findings have been reported in research which also focuses on the relationships between game demands and positional differences (Andrzejewski et al. 2016; Clarke et al. 2018; Datson et al. 2017; Jagim et al. 2020; Lockie et al. 2018; Sausaman et al. 2019).

2.4 Changes in Demands across a Soccer Season

Morgans et al. (2014)

This study examined changes in physical match performance of five players from an English Championship League team across the competitive season and examined the effect of team possession. Sprint and high intensity distances and frequency of efforts were all greatest in early-season, and were significantly reduced in both mid-and-late-season phases (all $p < 0.0001$). None of these variables were, however, related to team possession (p range = 0.2759 to 0.7411). Total distance covered on the other hand was sustained and did not significantly change over the season phases ($p = 0.9219$), but it was negatively associated with possession ($p = 0.0080$). This association suggests that physical demands were lower when this team was in possession of the ball. In summary, evidence of residual fatigue at mid-and-late-season was obtained from sprint and high intensity variables. Given possession was associated with a reduced total distance covered during matches, it may be speculated that better quality teams are able to maintain possession for longer periods of matches and thus require less recovery time due to reduced physical match demands.

Anderson et al. (2016)

Muscle glycogen is the predominant energy source for soccer match play, though its importance for soccer training (where lower loads are observed) is not well known. In an attempt to better inform CHO guidelines, we quantified TL in English Premier League soccer players (n = 12) during a one-, two- and three-game week schedule (weekly training frequency was four, four and two, respectively). In a one-game week, TL was progressively reduced ($P < 0.05$) in 3 days prior to match day (total distance = 5223 ± 406, 3097 ± 149 and 2912 ± 192 m for day 1, 2 and 3, respectively). Whilst daily TL and periodization was similar in the one- and two-game weeks, total accumulative distance (inclusive of both match and TL) was higher in a two-game week (32.5 ± 4.1 km) versus one-game week (25.9 ± 2 km). In contrast, daily training total distance was lower in the three-game week (2422 ± 251 m) versus the one- and two-game weeks, though accumulative weekly distance was highest in this week (35.5 ± 2.4 km) and more time ($P < 0.05$) was spent in speed zones >14.4 km · h−1 (14%, 18% and 23% in the one-, two- and three-game weeks, respectively). Considering that high CHO availability improves physical match performance but high CHO availability attenuates molecular pathways regulating training adaptation (especially considering the low daily customary loads reported here, e.g., 3–5 km per day), we suggest daily CHO intake should be periodised according to weekly training and match schedules.

Esco et al. (2014)

This study was conducted to determine if the Polar FT40 could accurately track changes in VO2max in a group of female soccer players. Predicted VO2max (pVO2max) via the Polar FT40 and observed VO2max (aVO2max) from a maximal exercise test on a treadmill were determined for members of a collegiate soccer team (n = 20) before and following an 8-week endurance training protocol. Predicted (VO2max and aVO2max measures were compared at baseline and within 1 week post-training. Change values (i.e., the difference between pre to post) for each variable were also determined and compared. There was a significant difference in aVO2max (pre = 43.6 ± 2.4 ml · kg · min−1, post = 46.2 ± 2.4 ml · kg · min−1, $P < 0.001$) and pVO2max (pre = 47.3 ± 5.3 ml · kg · min−1, post = 49.7 ± 6.2 ml · kg · min−1, $P = 0.009$)

following training. However, predicted values were significantly greater at each time point compared to observed values ($P < 0.001$ at pre and $P = 0.008$ at post). Furthermore, there was a weak correlation between the change in aVO2max and the change in pVO2max ($r = 0.18$, $P = 0.45$). The Polar FT40 does not appear to be a valid method for predicting changes in individual VO2max following 8 weeks of endurance training in female collegiate soccer players.

Favero et al. (2018)

Periodization optimizes training responses to improve performance. However, college soccer presents a unique challenge to periodized approaches because of a short pre-season and condensed match schedule. Academic challenges of class time and intensive examination schedules impact athlete's sleep and interfere with full recovery often leaving athletes fatigued and tired during and at the end of the season. Ultimately, this article outlined a model system to organize periodized training over an entire year, including summer training, preseason, and the competitive collegiate season. Practical suggestions were offered to address academic and seasonal challenges while preventing injury, avoiding burnout, and late season performance declines.

Jeong et al. (2011)

The aim of this study was to quantify the physiological loads of programmed “pre-season” and “in-season” training in professional soccer players. Data for players during each period were included for analysis (pre-season, n = 12; in-season, n = 10). We monitored physiological loading of training by measuring HR and rating of perceived exertion (RPE). TLs were calculated by multiplying RPE score by the duration of training sessions. Each session was sub-categorized as physical, technical/tactical, physical and technical/tactical training. Average physiological loads in pre-season (HR 124 ± 7 beats · min−1; TL 4343 ± 329 Borg scale · min) were higher compared with in-season (HR 112 ± 7 beats · min−1; TL 1703 ± 173 Borg scale ·

min) ($P < 0.05$) and there was a greater proportion of time spent in 80–100% maximum HR zones (18 ± 2 vs. 5 ± 2%; $P < 0.05$). Such differences appear attributable to the higher intensities in technical/tactical sessions during pre-season (pre-season: HR 137 ± 8 beats · min^{-1}; TL 321 ± 23 Borg scale · min; in-season: HR 114 ± 9 beats · min^{-1}; TL 174 ± 27 Borg scale · min; $P < 0.05$). These findings demonstrate that pre-season training is more intense than in-season training. Such data indicate that these adjustments in load are a direct attempt to deliver training to promote specific training adaptations.

Malone et al. (2015)

To quantify the seasonal TL completed by professional soccer players of the English Premier League. Typical daily TL (ie, total distance, high-speed distance, percent maximal HR [%HRmax], RPE load) did not differ during each week of the preseason phase. However, daily total distance covered was 1304 (95% CI 434–2174) m greater in the 1st mesocycle than in the 6th. %HRmax values were also greater (3.3%, 1.3−5.4%) in the 3rd mesocycle than in the first. Furthermore, TL was lower on the day before match (MD-1) than 2 (MD-2) to 5 (MD-5) d before a match, although no difference was apparent between these latter time points. The authors provide the 1st report of seasonal TL in elite soccer players and observed that periodization of TL was typically confined to MD-1 (regardless of mesocycle), whereas no differences were apparent during MD-2 to MD-5. Future studies should evaluate whether this loading and periodization are facilitative of optimal training adaptations and match-day performance.

Oliveira et al. (2019)

Top European soccer teams that play in UEFA competitions often participate in one, two- or three-games per week. Therefore, it is necessary to ensure optimal match-day performance and full recovery. The aim of this study was to quantify internal and ETL within five microcycles: M1 and M2 – one-game weeks; M3 and M4 – two-game weeks; M5 – three-game week). Thirteen elite soccer players participated in this study. A GPS was used to measure the total distance covered and distances of different exercise training zones (1–5), the session ratings of perceived exertion sRPE scores and the amount of CK created during daily training sessions for the 2015–2016 in-season period. The data were analysed with respect to the number of days prior to a given match. The main results indicate that there was a significant difference in training intensity for zone 1 between M2 and M4 (4010.2 ± 103.5 and 4507.6 ± 133.0 m, respectively); a significant difference in training intensity for zone 3 between M1 and M5 (686.1 ± 42.8 and 801.2 ± 61.2 m, respectively); a significant difference in the duration of the training sessions and matches between M2 and M5 (69.2 ± 2.1 and 79.6 ± 2.3) and M3 and M5 (69.7 ± 1.0 and 79.6 ± 2.3); and finally, there was a significant difference in CK between M3 and M2 (325.5 ± 155.0 and 194.4 ± 48.9). Moreover, there was a significant decrease in TL in the last day prior to a match, for all microcycles and all variables. There was no significant difference with respect to s-RPE. This study provides the first report of daily external and ITLs and weekly accumulated load (training sessions and match demands) during one, two, and three-game week schedules in a group of elite soccer players. Expected significant differences are found in daily and accumulated loads for within- and between-game schedules. A similar pattern is exhibited for one- and two-game week microcycles regarding the day before the match, which exhibits a decrease in all variables. Despite the different number of games played per week, TL remain similar between microcycles for zone 2 and 5, plus s-RPE.

Silva et al. (2015)

The purpose of this portion of Silva et al. (2015)'s project was to present a case study to design, execute, and evaluate the use of HR monitors as a tool for periodization in a Division I Men's Soccer team across a competitive season. The periodization schedule was created and based upon ITL information gathered from HR monitors and anchored to known periodization goals as well as coach and team-specific goals. Upon analyzing the data it was shown that, throughout the season, scheduled TLs deviated slightly from the periodization schedule but, in large part, were adhered to and tended to yield the desired effect of sustained maintenance of fitness levels. In turn, this seems to have impacted the team ‘on-the-pitch’ as the team went on to have one of the most successful seasons in recent program history. Lessons learned from this case-study analysis should serve to strengthen the coaching staff’s knowledge regarding HR monitoring and how to best utilize this method in creating an optimal periodization schedule. As the review of literature and case study suggest, the knowledge of ITL can be a useful tool to a coach or trainer seeking optimize a team or player’s potential and ultimately, the decision regarding the method of acquirement and use of ITL, should be made upon the individual necessities/desires of the coach or trainer. Altogether, when TL is accurately monitored (whether it be via sRPE or HR monitors) more suitable approaches for maintaining and improving fitness levels and performance can be suggested for implementation. Additionally, it may be beneficial to examine the common physical demands and TLs associated with specific phases of a competitive season for teams and specific position groups in order to further periodization goals and outcomes.

2.4.1 Summary of Changes in Demands across a Soccer Season

In addition to quantifying TL across sports using mixed-methods, monitoring fluctuations in ITL and ETL over the course of a competitive season can provide further insight for optimizing performance (Anderson et al. 2016; Esco et al. 2014; Favero et al. 2018; Jeong et al. 2011; Malone et al. 2015; Morgans et al. 2014; Oliveira et al. 2019; Silva et al. 2015). Although TL values are generally constant across different sports (i.e. low, moderate, intense), collegiate athletics are unique. In addition to being athletes, collegiate athletes are also full-time students which is an additional external stressor. However, TL monitoring can be utilized to select more suitable approaches for maintaining and improving fitness levels, preventing injury, avoiding burnout, and avoiding performance declines throughout the course of a competitive season (Favero et al. 2018 and Silva et al. 2015).

Generally, there are three distinct phases of an athletic training cycle. Off-season, pre-season, and in-season are the three phases and each has a separate focus. During the off-season, high volumes of jogging, sprinting, and lifting weights are usually implemented in order to increase athlete's general fitness overall. The pre-season phase is generally further separated into an early and late phase. During the early pre-season phase, the focus shifts to more sport-specific running distances and intensities and weightlifting in order to strengthen the primary muscle groups used during competition. The late pre-season phase is generally when "pre-season camp" occurs and upwards of two training sessions often occur within a single 24-hour period. Additionally, "pre-season camp" is generally 7-10 days and focuses on increasing overall fitness and skill through more frequent practicing which results in higher running distance, higher running intensities, and increased skill development. Once the competitive season begins, there are five primary phases at the collegiate level; exhibition, non-conference, conference, conference championship tournament, NCAA championship tournament.

Research suggests that TL is progressively reduced ($p < 0.05$) in the three days prior to match day (Anderson et al. 2016). Moreover, there was a significant decrease in TL in the last day prior to a match, for all microcycles and all variables (Oliveira et al. 2019). Furthermore, TL was lower on the day before match (MD-1) than 2 (MD-2) to 5 (MD-5) d before a match, although no difference was apparent between these latter time points (Malone et al. 2015). Whilst daily TL and periodization was similar in the one- and two-game weeks, this measure was found to be significantly higher in a two-game week versus one-game week. In contrast, daily training TL was lower in the three-game week versus the one- and two-game weeks, though accumulative TL was highest in this week ($p < 0.05$) (Anderson et al. 2016). Compared with average in-season TL values, TLs in pre-season have been found to be significantly higher ($p < 0.05$) (Jeong et al.

2011). However, average TLs (both ITL and ETL) do not differ during each week of the preseason phase ($p > 0.05$) (Malone et al. 2015).

Total distance covered on the other hand was sustained and did not significantly change over the in-season phases ($p = 0.9219$), but it was negatively associated with possession ($p = 0.0080$) (Morgans et al. 2014). Total accumulative match distance was higher in a two-game week versus one-game week ($p < 0.05$). In contrast, daily training total distance was lower in the three-game week (2422 ± 251 m) versus the one- and two-game weeks, though accumulative weekly distance was highest in this week ($p < 0.05$) (Anderson et al. 2016). When examining each week of the pre-season phase, it has been reported that daily total distance covered was 1304 (95% CI 434–2174) m greater in the 1st mesocycle than in the 6th (Malone et al. 2015). Sprint and high intensity distances and frequency of efforts were all greatest in early-season, and were significantly reduced in both mid-and-late-season phases ($p < 0.001$) (Morgans et al. 2014). Additionally, when comparing durations in speed zones across one-, two-, and three-game weeks it has been reported that more time ($p < 0.05$) was spent in speed zones >14.4 km · h−1 (14%, 18% and 23% in the one-, two- and three-game weeks, respectively) (Anderson et al. 2016)

Research has shown that before and following an 8-week endurance training protocol there is a significant difference in aVO2max ($p < 0.001$) and pVO2max ($p = 0.009$) following training (Esco et al. 2014). During the pre-season phase, %HRmax values have been found to be greater (3.3%, 1.3−5.4%) in the 3rd mesocycle than in the first (Malone et al. 2015). Additionally, a greater proportion of time spent in 80–100% maximum HR zones is significantly greater in the pre-season when compared to the in-season phase ($p < 0.05$). Such differences appear attributable to the significantly higher intensities in technical/tactical sessions during pre-season ($p < 0.05$) (Jeong et al. 2011). The main results indicate that there was a significant difference in training intensity for HR zone 1 between M2 and M4; a significant difference in training intensity for HR zone 3 between M1 and M5. However, a significant difference in the duration of the training sessions and matches between M2 and M5, and M3 and M5 may influence the findings from above. Additionally, as the competitive schedule becomes more congested, research has observed significant differences in CK between one- and two-game weeks ($p < 0.05$) (Oliveira et al. 2019).

Overall, research regarding TL monitoring across specific phases of a soccer season has also been well-supported, well-reported, and well-explored. Furthermore, significant differences in ITL and ETL across these phases have been reported (Anderson et al. 2016; Esco et al. 2014; Favero et al. 2018; Jeong et al. 2011; Malone et al. 2015; Morgans et al. 2014; Oliveira et al. 2019; Silva et al. 2015). However, there is a significant gap in the current literature because similar investigations have not been conducted within the women's college soccer population. Furthermore, position based ITL and ETL changes across a competitive season have not been explored within any soccer population to date. Investigations focused on this area of research can provide polarizing insights which can improve our current approaches for maintaining and improving fitness levels, preventing injury, avoiding burnout, and avoiding performance declines throughout the course of a competitive season.

CHAPTER III

METHODS AND PROCEDURES

The purpose of this study was to investigate position- and season phase-specific differences in internal and external training loads between five distinct phases over the course of a NCAA Division I women's soccer seasons.

3.1 Preliminary Procedures

Coaches from the Oklahoma State University women's soccer team were contacted by email and face-to-face conversation to inform them about the purpose of this study. Additionally, the primary investigator requested that the coaches provide access to the team's Polar Team Pro online database in order to access their data for descriptive and quantitative purposes. All data for this research was retroactive (archival) in nature. Although Polar Team Pro offers 35 measures regarding ITL and ETL, the primary investigator has limited the data to be analyzed to include ITL measures (e.g., HRavg, HRmax, duration in HR zones 1-5, training load, and calories burned) and ETL measures (e.g., total distance, high speed running distance, distance in speed zones 1-5, number of sprints, intense speed changes). These measures have been utilized in previous soccer research to assess fitness and performance (Alexander et al. 2014; Andrzejewski et al. 2016; Bangsbo et al. 2014; Bradley et al. 2014; Clarke et al. 2018; Datson et al. 2017; Jagim et al. 2020; Krustrup et al. 2005; Lockie et al. 2018; Martínez-Lagunas et al. 2014; Oliveira et al. 2019; Sausaman et al. 2019; Silva et al. 2015). Archived ITL and ETL data from 80 games over the course of five soccer seasons were analyzed for this investigation. All data were recorded with

Polar Heart Rate monitors (Polar Team System, Polar Electro, Kempele Finald). ITL data included; HRavg, HRmax, duration in HRzones 1-5, training load, and calories. ETL data included; total distance, distance in speed zones 1-4, volume of sprints, and number of accelerations and decelerations Additionally, this data was further separated based on natural trends or phases of a NCAA Division I women's soccer competitive season [pre-season, exhibition, non-conference, conference, Big XII championship series, NCAA tournament].

3.2 Participants

Archived data from 116 (N = 116) Oklahoma State University women's soccer athletes (age range 18 - 22.5; height 66.37 ± 2.23 in.; body mass 134.05 ± 14.74 lbs.) from approximately 80 games across five competitive seasons were used for descriptive and comparative purposes. By position, data was analyzed for (n = 17) goalkeepers (GK), (n = 36) defenders (D), (n = 41) midfielders (M), and (n = 22) forwards (F). By phase, data was analyzed for athletes who had participated in at least half (45 minutes) of a game. Data for these athletes were collected by members of the team's coaching staff and voluntarily provided to the primary investigator for data analysis.

Participants were included within this study if they were an OSU women's soccer athlete between 2016-2021 and participated in at least half (45 minutes) of a game. Participation in games was validated through the use of NCAAmanager.com, the National Collegiate Athletic Association's official competition statistics database (NCAA). Participants were excluded from this study if they were not an OSU women's soccer athlete between 2016-2021 and/or did not participate in at least half (45 minutes) of a game.

3.3 Procedures

3.3.1 Consent

Consent was obtained by the Institutional Review Board at Oklahoma State University prior to the analysis of this data (Appendix A). The data collected for this study included the following descriptive information; season phases, ITL measures, and ETL measures. No actual contact with human subjects was involved in this research. Thus, due to the retrospective nature of the data collected this study was qualified for exempt status under the guidelines set forth by the Institutional Review Board at Oklahoma State University (IRB-21-230). No comparisons were made between individual athletes. In addition all data was stored on an encrypted and password secure hard drive and an online database provided by Polar Team Pro which only the primary investigator and team personnel had access to.

3.3.2 Internal and External Training Loads

The athlete's ETL and ITL were monitored and quantified by means of portable GPS devices (Polar Team System, Polar Electro, Kempele Finald) operating at a sampling frequency of 10 Hz and incorporating a 200 Hz 3D triaxial accelerometer (Polar). A 10 Hz sampling frequency provided 10 measurements of each ETL and ITL variable per second. The average of those 10 measurements is represented in the raw data recorded by the GPS devices. Each player wore a special harness that enabled this device to be fitted around the mid-chest and placed directly over their sternum. The GPS devices were activated 15 minutes before the start of each game, in accordance with the manufacturer's instructions (Polar). At the conclusion of each game, the Polar Pro Team Dock® was used to charge the Polar Pro sensors and sync data from them to the Polar Team Pro app and Polar Team Pro web service. It also serves as a base and charger for the iPad® used to track training loads. The Polar Pro sensor measures extensive player performance data, records the data in detail and sends it live to iPad® via *Bluetooth*® Smart allowing an individual to follow real-time information during training (Polar).

3.3.3 Internal Training Loads (ITLs)

ITLs were used to assess internal contributors to performance. These values were; average heart rate (HRavg), maximum heart rate (HRmax), duration in HR zones (HRZ_1, HRZ_2, HRZ_3, HRZ_4, HRZ_5), training load, and calories burned. HRavg is a measurement which includes the duration of an event and the athlete's heart rate at each minute during that event. Each athlete's heart rate was measured at 10Hz (10 times per second) and then aggregated after each minute to reflect their HRavg. HRmax is a measurement which reflects an athlete's maximal heart rate throughout the course of an event. Similarly to the HRavg measurement, each athlete's heart rate was measured 10 times per second with the highest HR being reported for that interval. HR zones were predetermined and validated zones established by Polar® which reflect the intensity of an event. HRZ_1 is referred to as the "very light" training zone. This zone is characterized by 50-60% of an athlete's HRmax. HRZ_2 is referred to as the "light" training zone. This zone is characterized by 60-70% of an athlete's HRmax. HRZ_3 is referred to as the "moderate" training zone. This zone is characterized by 70-80% of an athlete's HRmax. HRZ_4 is referred to as the "hard" training zone. This zone is characterized by 80-90% of an athlete's HRmax. HRZ_5 is referred to as the "maximum" training zone. This zone is characterized by 90-100% of an athlete's HRmax. The duration spent within these zones further reflects the intensity of an event. The training load measure calculated by Polar® takes into account several personal aspects. These include; age, sex, weight, VO2max, an individual's training history, and the type of sport an individual participates in (Polar). Calories burned measures the intensity of an event based on an individual's energy expenditure and the information included within their training load calculation.

3.3.4 External Training Loads (ETLs)

ETLs were used to assess external contributors to performance. These values were; total distance, distance in speed zones 1-5 (SZ1-5), number of sprints, and intense speed changes. Total distance is a measurement which includes the distance an athlete travelled during any given event. Distance in speed zones 1-5 is a measures the distance an athlete travelled at specific velocities (Polar). Speed zone 1 is characterized by distances traveled between 2.0 and 3.49 miles per hour. Speed zone 2 is characterized by distances traveled between 3.5 and 5.99 miles per hour. Speed zone 3 is characterized by distances traveled between 6.0 and 8.99 miles per hour. Speed zone 4 is characterized by distances traveled between 9.0 and 10.49 miles per hour. Speed zone 5 is characterized by distances traveled at ≥ 10.5 miles per hour. Additionally, these values are predetermined by Polar® for highly fit individuals. Number of sprints is a measurement which includes all acceleration values over 2.8 m/s^2. The length of these accelerations can vary from a three-step explosive movement to a ≥ 20m sprint. Intense speed changes are any acceleration at or above 3.5 m/s^2 and/or any deceleration at or below -3.5 m/s^2.

3.3.5 Season Phases

Season phases were determined by trends in the team's competitive season. Although there are three primary training phases (off-season, pre-season, and in-season), only the pre-season and in-season phases were used for data analysis. The pre-season phase typically consists of 1-4 weeks of focused training leading up to the competitive season. This phase of the season typically occurs twice each year, at the beginning of the spring and fall seasons. For the intents and purposes of this investigation, games during this time period which did not count toward the team's win/loss record were considered 'Exhibition'. During this phase data was analyzed for athletes who had participated in at least half (45 minutes) of a game.

The in-season phase consisted of five separate phases; exhibition, non-conference, conference, conference championship series, and the NCAA tournament. The exhibition phase generally consists of one unofficial game under regular game conditions played against an out of conference opponent and accounts for 6% of the regular season competitive schedule. Additionally, this event usually marks the end of the pre-season and beginning of the competitive season. However, these events were distinguished as an individual phase in order to better compare them with the remaining phases. During this phase data was analyzed for athletes who had participated in at least half (45 minutes) of a game.

The non-conference phase follows the exhibition phase and generally consists of official games under regular game conditions played against out of conference and in-conference opponents. These games generally account for 47% of the regular season competitive schedule. Outcomes from in-conference opponents faced in the non-conference phase do not count towards conference standings. However, all outcomes from non-conference, conference, and conference championship series games influencing seeding for the NCAA tournament. During this phase data was analyzed for athletes who had participated in at least half (45 minutes) of a game.

The conference phase follows the non-conference phase and generally consists of official games under regular game conditions played against in-conference opponents. These games generally account for 47% of the regular season competitive schedule. Outcomes from this phase of the season influence seeding for the conference championship series and NCAA tournament. At the conclusion of the regular season the conference championship series is played. Conference opponents are faced again in this phase of the season and the victor of the conference championship series receives an automatic bid into the NCAA tournament. At most, these games generally account for 25% of the post-season competitive schedule. During this phase data was analyzed for athletes who had participated in at least half (45 minutes) of a game.

The NCAA tournament phase follows the conference championship series phase. At most, these games generally account for 75% of the post-season competitive schedule. Additionally, all NCAA member schools compete in the NCAA tournament. During this phase data was analyzed for athletes who had participated in at least half (45 minutes) of a game.

3.4 Statistical Analysis

Descriptive results are presented as means ± standard deviations. A two-way multivariate analysis of variance (MANOVA) was used to determine if there were differences between the five seasonal phases for position groups. All of the statistical analyses were performed using Statistics Package for the Social Sciences (version 24.0, SPSS Inc. Chicago, IL) for Windows. Statistical significance was set at $P < 0.05$.

CHAPTER IV
FINDINGS

4.1 Descriptive Statistics

Archived data from 116 Oklahoma State University women's soccer athletes were analyzed to achieve the purpose of this dissertation. In total, 797 total data points from 80 games were analyzed from the current sample. Descriptive statistics for Position and Season Phase can be found in Table 1. and Table 2.

Table 1. Positional Descriptive Statistics

Position	Data Points	Percent of Sample	Cumulative Percent
Defender	233	29.24%	29.24%
Midfielder	221	27.72%	56.96%
Forward	343	43.04%	100.00%
Total Data Points	797		

Table 2. Season Phase Descriptive Statistics

Season Phase	Games	Percent of Sample	Cumulative Percent
Exhibition	16	20.00%	20.00%
Non-Conference	24	30.00%	50.00%
Conference	32	40.00%	90.00%
Big XII	4	5.00%	95.00%
NCAA	4	5.00%	100.00%
Total Games	80		

4.2 Effects of Position and Season Phase Interactions on Internal and External Loads

A two-way Multivariate Analysis of Variance (MANOVA) was performed to analyze the effect of Position and Season Phase on internal and external loads. The MANOVA revealed that there was not a statistically significant interaction between the effects of Position and Season Phase on internal and external loads F(168, 5739) = 1.142, p = .103; Wilks' Λ = .781.

Simple main effects analysis showed that Position (Defender, Midfielder, Forward) did have a statistically significant effect on internal and external loads F(42, 1524) = 7.694, p = .000; Wilks' Λ = .681. Additionally, large effect sizes were observed for this analysis $\eta p^2 = 0.175$.

Simple main effects analysis showed that Season Phase (Exhibition, Non-Conference, Conference, B12, NCAA) did have a statistically significant effect on internal and external loads F(84, 3012) = 3.785, p = .000; Wilks' Λ = .673. Additionally, a moderate effect size was observed for this analysis $\eta p^2 = 0.094$.

Table 3. Effects of Position and Season Phase Multivariate Tests

Multivariate Tests

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Intercept	Pillai's Trace	.998	18410.745	21.000	762.000	.000	.998
	Wilks' Lambda	.002	18410.745	21.000	762.000	.000	.998
	Hotelling's Trace	507.383	18410.745	21.000	762.000	.000	.998
	Roy's Largest Root	507.383	18410.745	21.000	762.000	.000	.998
Position	Pillai's Trace	.343	7.528	42.000	1526.000	.000	.172
	Wilks' Lambda	.681	7.694	42.000	1524.000	.000	.175
	Hotelling's Trace	.434	7.861	42.000	1522.000	.000	.178
	Roy's Largest Root	.326	11.834	21.000	763.000	.000	.246
Season Phase	Pillai's Trace	.369	3.705	84.000	3060.000	.000	.092
	Wilks' Lambda	.673	3.785	84.000	3012.279	.000	.094
	Hotelling's Trace	.427	3.864	84.000	3042.000	.000	.096
	Roy's Largest Root	.225	8.191	21.000	765.000	.000	.184
Position * Season Phase	Pillai's Trace	.242	1.140	168.000	6152.000	.106	.030
	Wilks' Lambda	.781	1.142	168.000	5739.308	.103	.030
	Hotelling's Trace	.253	1.144	168.000	6082.000	.101	.031
	Roy's Largest Root	.080	2.937	21.000	769.000	.000	.074

Table 4. Effects of Position and Season Phase Tests of Between-Subjects Effects

Tests of Between-Subjects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Observed Power[x]
Position * Season Phase	HR avg [bpm]	710.682	8	88.835	1.182	.307	.012	9.458
	HR max [bpm]	1466.430	8	183.304	1.833	.068	.018	14.667
	HR avg [%]	171.956	8	21.494	.857	.553	.009	6.857
	HR max [%]	218.675	8	27.334	1.001	.433	.010	8.011
	Time in HRZ1	6294962.017	8	786870.252	1.487	.158	.015	11.898
	Time in HRZ2	2746104.437	8	343263.055	1.191	.301	.012	9.528
	Time in HRZ3	3229980.144	8	403747.518	1.059	.390	.011	8.470
	Time in HRZ4	5200766.005	8	650095.751	.901	.515	.009	7.205
	Time in HRZ5	14797243.830	8	1849655.479	1.876	.061	.019	15.012
	Total distance [yd]	37002961.390	8	4625370.174	.802	.601	.008	.378
	Sprints	2008.800	8	251.100	.781	.620	.008	.368
	Distance in SZ1	3954520.198	8	494315.025	1.328	.226	.013	.614
	Distance in SZ2	1647568.196	8	205946.024	.401	.920	.004	.191
	Distance in SZ3	674407.286	8	84300.911	.142	.997	.001	.092
	Distance in SZ4	205394.193	8	25674.274	.539	.827	.005	.253
	Distance in SZ5	707622.450	8	88452.806	.956	.470	.010	.451
	Training Load	11823.902	8	1477.988	.360	.941	.004	.174
	Calories [kcal]	238917.038	8	29864.630	.462	.883	.005	.218
	Number of accelerations	4.390	8	.549	1.728	.088	.017	.754
	Number of accelerations	44.871	8	5.609	.721	.673	.007	.339
	Number of accelerations	6.536	8	.817	.318	.959	.003	.157
	Number of accelerations	.000	8	.000	.	.	.	.

4.3 Effects of Position on Internal Loads

No significant Position x Season Phase interaction was observed for any measure of internal load. However, main effects for Position were observed for HRavg [bpm] (p = 0.000, ηp2 = 0.05), HRavg [%] (p = 0.000, ηp2 = 0.04), time in HRZ_1 (p = 0.000, ηp2 = 0.07), HRZ_2 (p = 0.000, ηp2 = 0.02), HRZ_3 (p = 0.050, ηp2 = 0.01), HRZ_4 (p = 0.001, ηp2 = 0.02), HRZ_5 (p = 0.004, ηp2 = 0.01), Training Load (p = 0.000, ηp2 = 0.02) and Calories (p = 0.000, ηp2 = 0.03).

Table 5. Effects of Position on Internal Loads Tests of Between-Subjects Effects

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Observed Power^{x}
Position	HR avg [bpm]	3176.875	2	1588.437	21.140	.000	.051	1.000
	HR max [bpm]	509.685	2	254.842	2.549	.079	.006	.510
	HR avg [%]	721.818	2	360.909	14.392	.000	.036	.999
	HR max [%]	8.629	2	4.314	.158	.854	.000	.074
	HRZ_1 Duration	28870800.800	2	14435400.400	27.284	.000	.065	1.000
	HRZ_2 Duration	4653142.984	2	2326571.492	8.073	.000	.020	.958
	HRZ_3 Duration	2286556.048	2	1143278.024	2.998	.050	.008	.582
	HRZ_4 Duration	11017584.220	2	5508792.112	7.632	.001	.019	.947
	HRZ_5 Duration	11095966.020	2	5547983.011	5.628	.004	.014	.860
	Training Load	66084.863	2	33042.431	8.042	.000	.020	.957
	Calories [kcal]	1409127.304	2	704563.652	10.895	.000	.027	.991

For HR Average [bpm], Bonferroni’s test revealed that Defenders had significantly higher HR Average [bpm] values than any other Position (p = 0.000), while Midfielders HR Average [bpm] values were significantly higher than Forwards (p = 0.004).

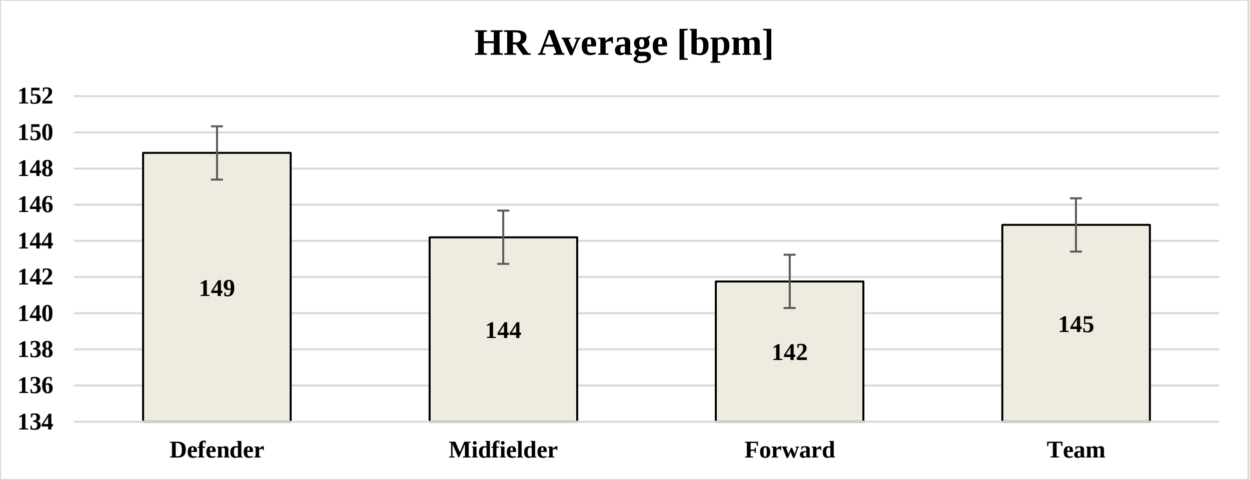

Figure 3. Comparison of differences in HR Average [bpm] between position groups.

For HR Average [%], Bonferroni’s test revealed that Defenders had significantly higher HR Average [bpm] (p = 0.000) values than any other Position.

Figure 4. Comparison of differences in HR Average [%] between position groups.

For HR Maximum [bpm], Bonferroni’s test revealed no significant differences between Positions (p = 0.082 – 1.000).

Figure 5. Comparison of differences in HR Maximum [bpm] between position groups.

For HR Maximum [%], Bonferroni’s test revealed no significant differences between Positions (p = 0.352 – 1.000).

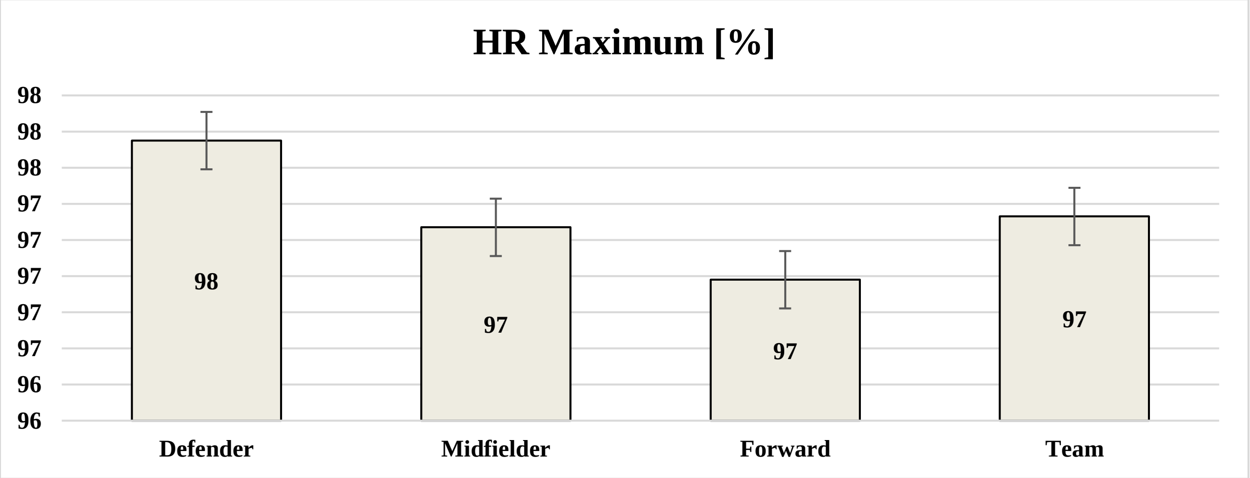

Figure 6. Comparison of differences in HR Average [%] between position groups.

For Heart Rate Zone 1 Duration, Bonferroni's test revealed significant differences between all Position groups (p = 0.000). Defenders spent significantly less time in HRZ1 than any other Position (p = 0.000) while Forwards spent significantly more time in HRZ1 than any other Position (p = 0.000).

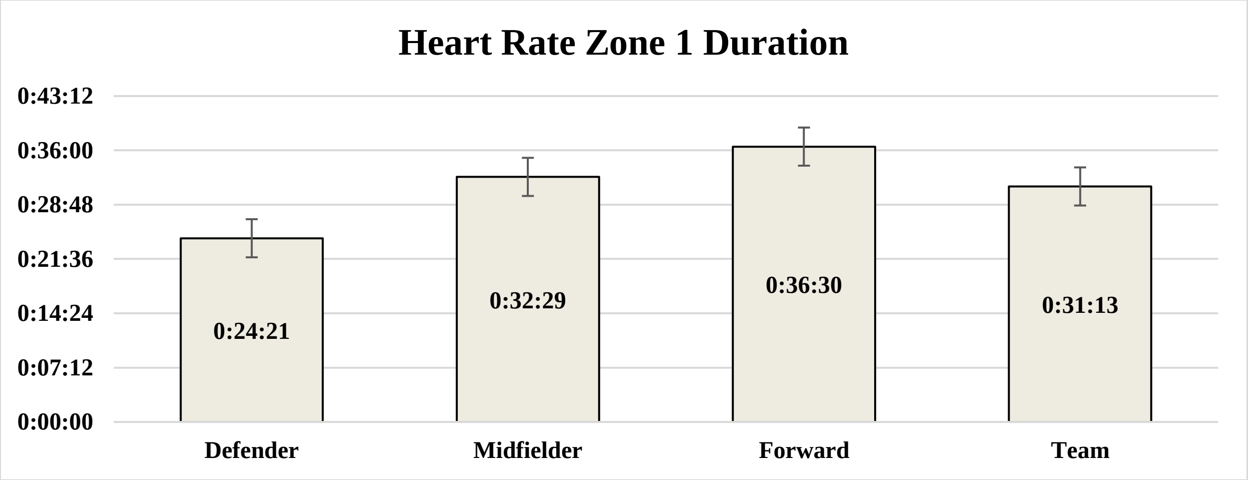

Figure 7. Comparison of differences in Heart Rate Zone 1 Duration between position groups.

For Heart Rate Zone 2 Duration, Bonferroni's test revealed significant differences between Defenders and all other positions (p = 0.000 - .002).

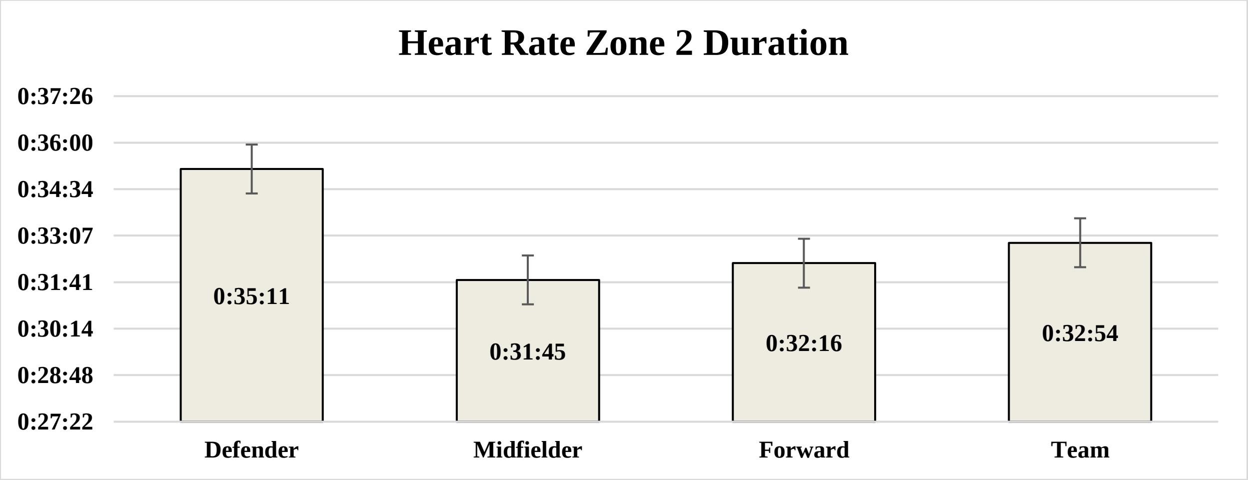

Figure 8. Comparison of differences in Heart Rate Zone 2 Duration between position groups.

For Heart Rate Zone 3 Duration, Bonferroni's test revealed significant differences between Defenders and Forwards (p = 0.005) and Midfielders and Forwards (p = 0.043).

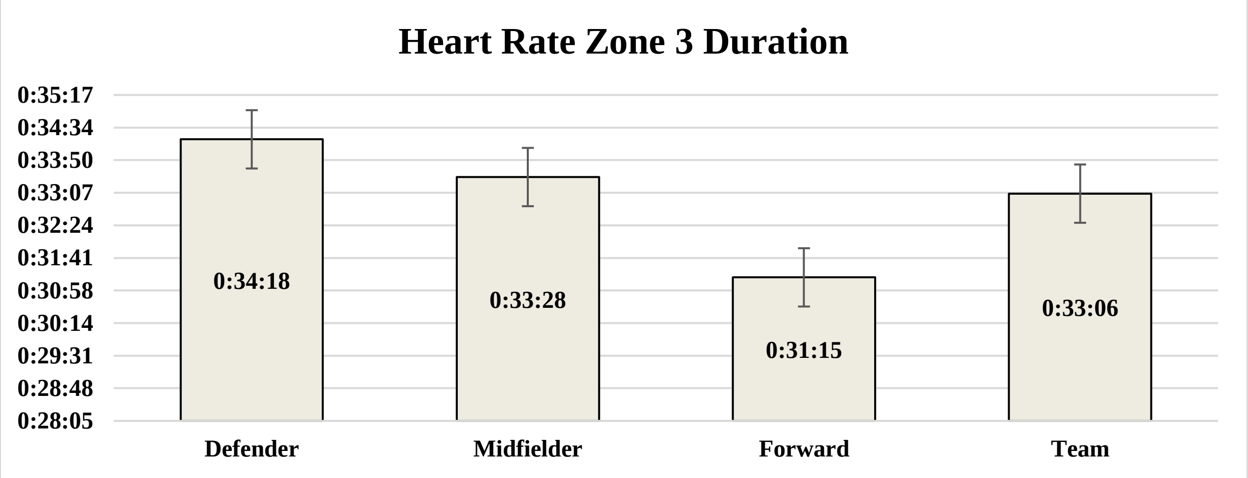

Figure 9. Comparison of differences in Heart Rate Zone 3 Duration between position groups.

For Heart Rate Zone 4 Duration, Bonferroni's test revealed significant differences between Defenders and Midfielders (p = 0.001) and Forwards and Midfielders (0.001).

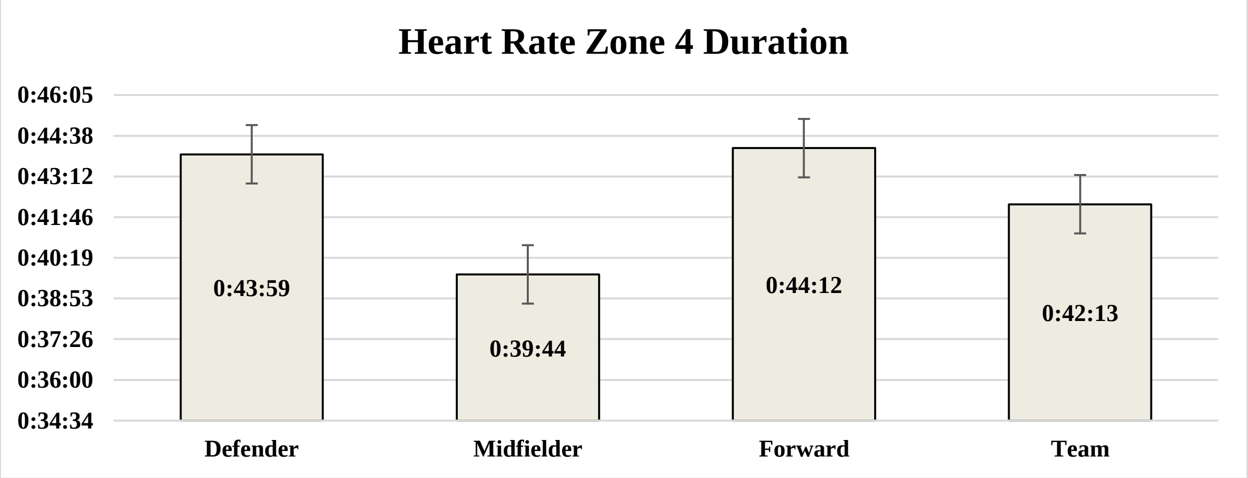

Figure 10. Comparison of differences in Heart Rate Zone 4 Duration between position groups.

For Heart Rate Zone 5 Duration, Bonferroni's test revealed significant differences between all Positions (p = 0.000 – 0.026).

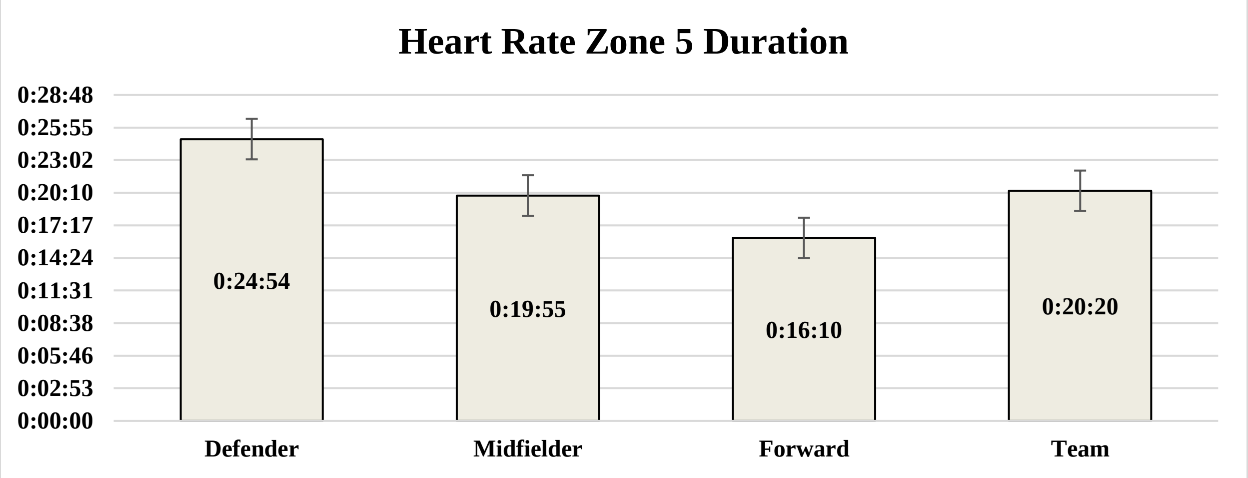

Figure 11. Comparison of differences in Heart Rate Zone 5 Duration between position groups.

For Training Load, Bonferroni's test revealed significant differences between Defenders and all other Positions (p = 0.000).

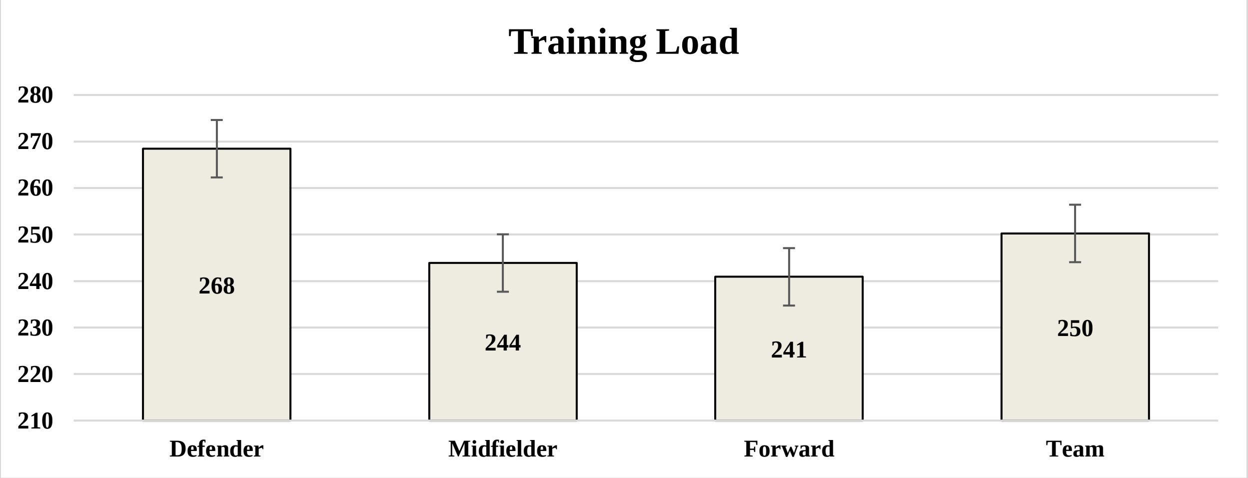

Figure 12. Comparison of differences in Training Load between position groups.

For Calories, Bonferroni's test revealed significant differences between Defenders and all other positions (p = 0.000).

Figure 13. Comparison of differences in Calories burned between position groups.

4.4 Effects of Position on External Loads

No significant Position x Season Phase interaction was observed for any measure of external load. However, main effects for Position were observed for Sprints (p = 0.000, ηp2 = 0.050), and Distance in Speed Zone 1 (p = 0.000, ηp2 = 0.027), 2 (p = 0.048, ηp2 = 0.008), 3 (p = 0.000, ηp2 = 0.035), 4 (p = 0.000, ηp2 = 0.068), and 5 (p = 0.000, ηp2 = 0.067), and Number of decelerations (-4.49 - -3.50 m/s^2) (p = 0.000, ηp2 = 0.029)**.**

Table 6. Effects of Position on External Loads Tests of Between-Subjects Effects

Tests of Between-Subjects Effects								
Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Observed Power
Position	Total distance [yd]	33001680.400	2	16500840.200	2.860	.058	.007	.561
	Sprints	13119.542	2	6559.771	20.404	.000	.050	1.000
	Distance in SZ1 [yd]	8229234.531	2	4114617.265	11.055	.000	.027	.992
	Distance in SZ2 [yd]	3129790.728	2	1564895.364	3.047	.048	.008	.589
	Distance in SZ3	16883747.950	2	8441873.974	14.239	.000	.035	.999
	Distance in SZ4	2728509.410	2	1364254.705	28.652	.000	.068	1.000
	Distance in SZ5	5189753.284	2	2594876.642	28.041	.000	.067	1.000
	Number of accelerations (-50.00 - -4.50 m/s²)	1.323	2	.661	2.083	.125	.005	.429
	Number of accelerations (-4.49 - -3.50 m/s²)	180.777	2	90.388	11.623	.000	.029	.994
	Number of accelerations (3.50 - 4.49 m/s²)	2.992	2	1.496	.583	.558	.001	.147
	Number of accelerations (4.50 - 50.00 m/s²)	.000	2	.	.	.	.	.

For Total Distance (yards), Bonferroni’s test revealed significant differences between Midfielders and Forwards (p = 0.020)

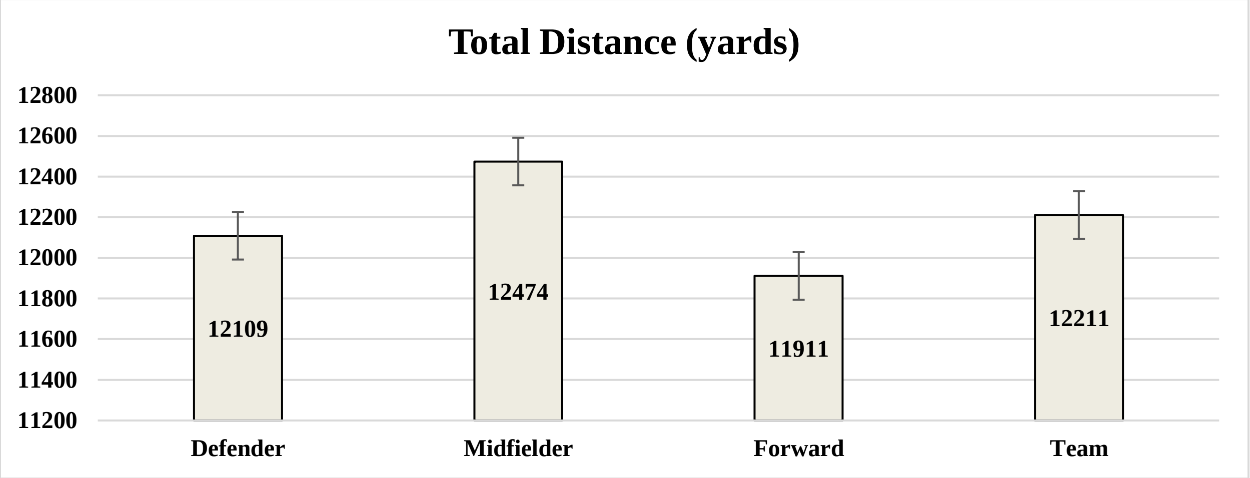

Figure 14. Comparison of differences in Total Distance (yards) between position groups.

For Volume of Sprints, Bonferroni’s test revealed significant differences between all Positions (p = 0.000).

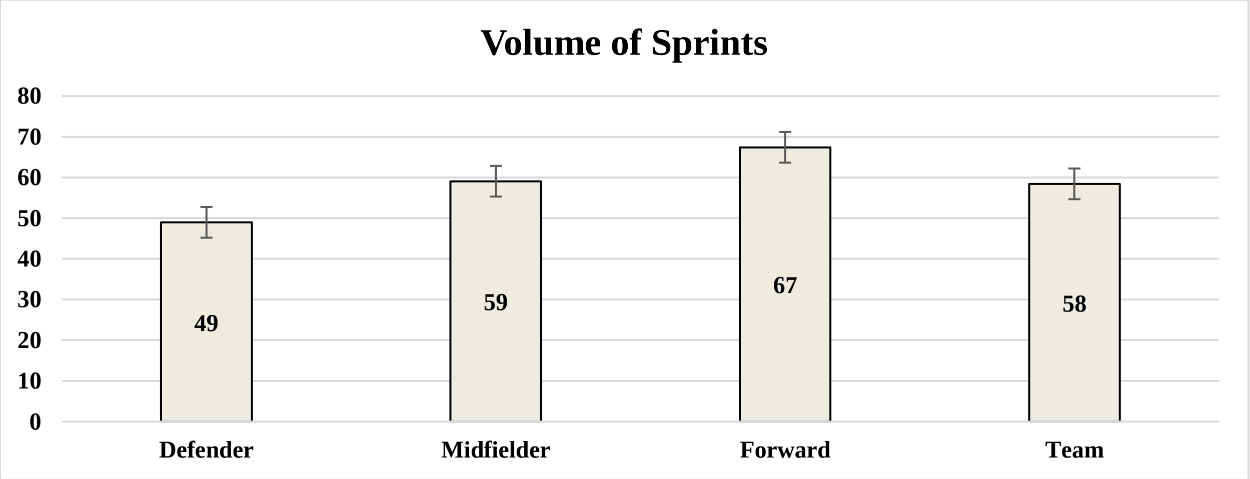

Figure 15. Comparison of differences in Sprints between position groups.

For Speed Zone 1 Distance, Bonferroni's test revealed significant differences between Defenders and all other Positions (p = 0.000). No significant differences were observed between Midfielders and Forwards (p = 0.051).

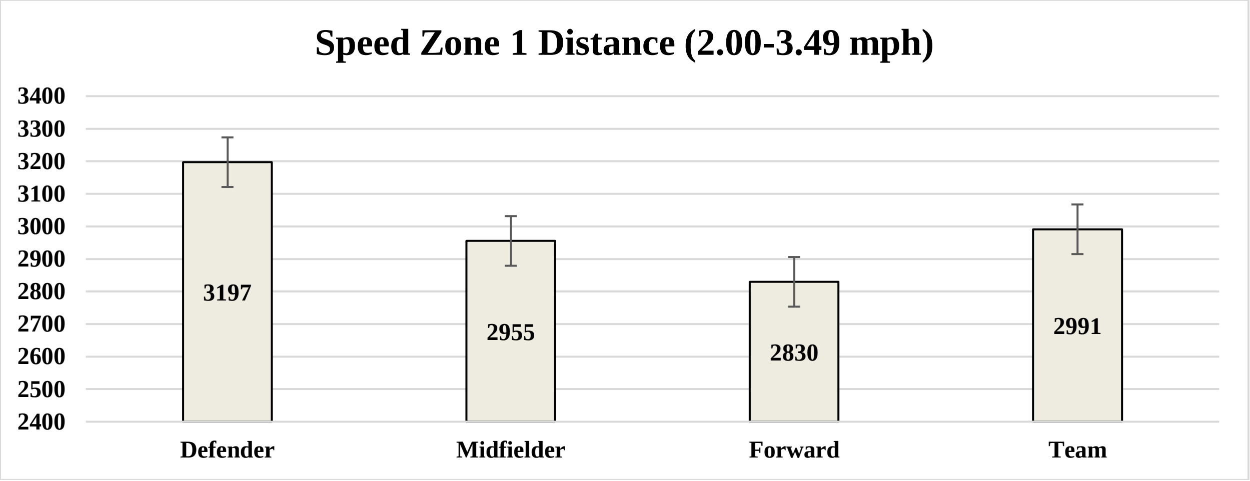

Figure 16. Comparison of differences in Speed Zone 1 Distance between position groups.

For Speed Zone 2 Distance, Bonferroni's test revealed significant differences between Forwards and Midfielders (p = 0.002).

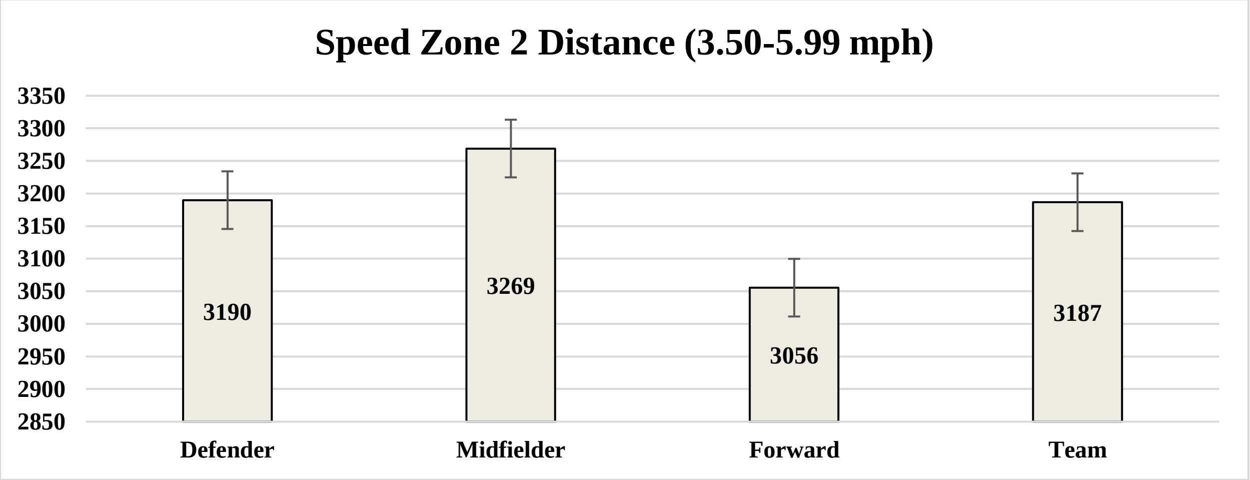

Figure 17. Comparison of differences in Speed Zone 2 Distance between position groups.

For Speed Zone 3 Distance, Bonferroni's test revealed significant differences between all Position groups (p = 0.000 – 0.010).

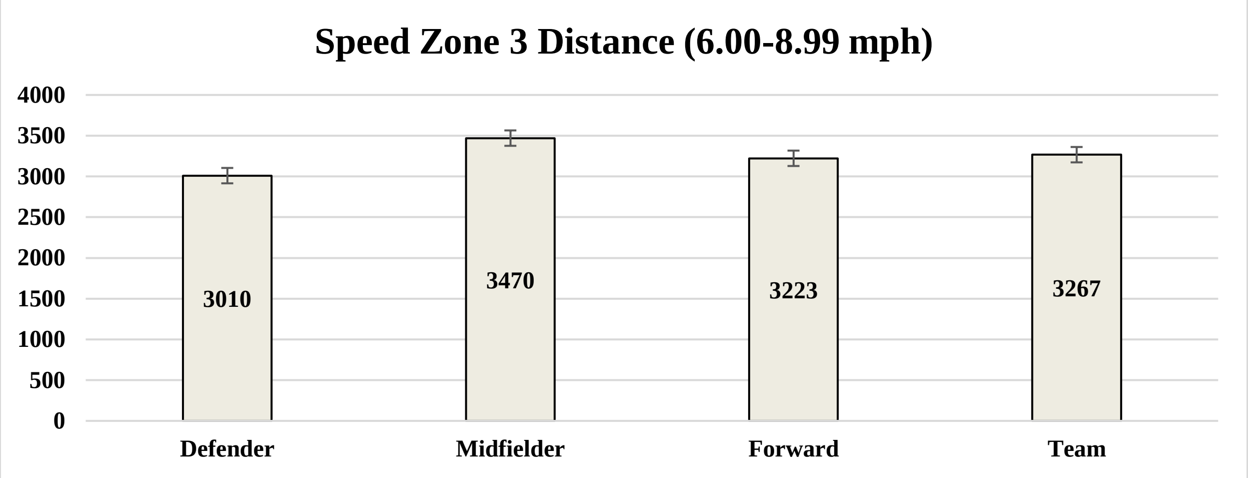

Figure 18. Comparison of differences in Speed Zone 3 Distance between position groups.

For Speed Zone 4 Distance, Bonferroni's test revealed significant differences between Defenders and all other Positions (p = 0.000).

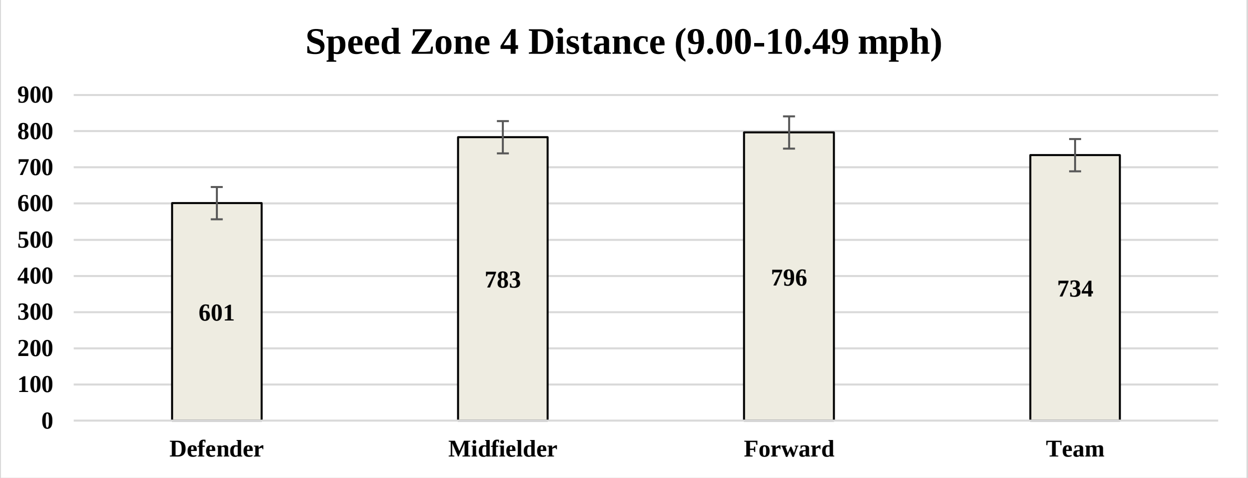

Figure 19. Comparison of differences in Speed Zone 4 Distance between position groups.

For Speed Zone 5 Distance, Bonferroni's test revealed significant differences between all Positions (p = 0.000).

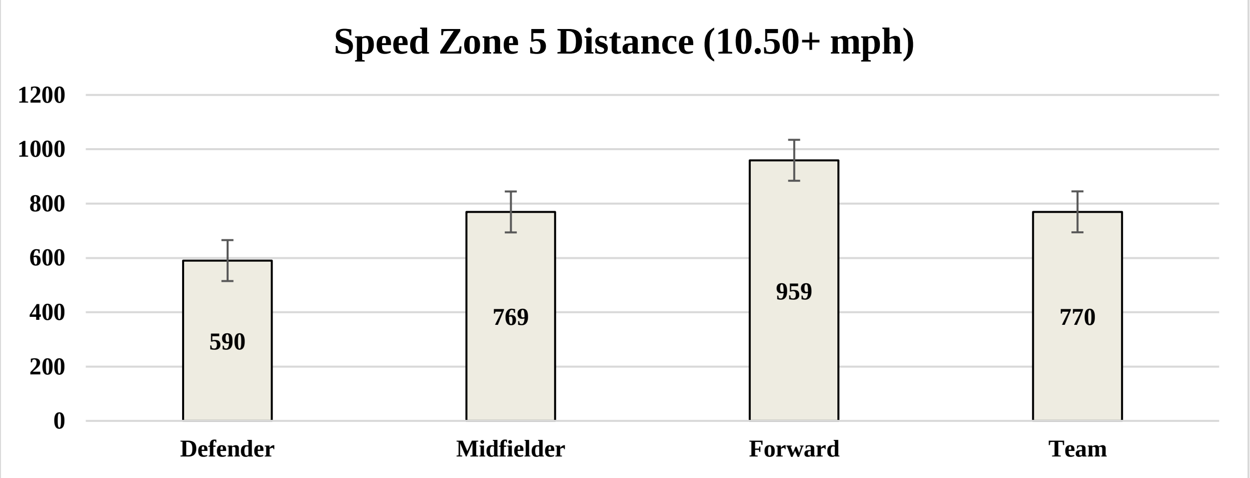

Figure 20. Comparison of differences in Speed Zone 5 Distance between position groups.

For Number of Accelerations (3.50 – 4.49 m/s2), Bonferroni's test revealed no significant differences between Positions (p = 0.292 – 1.000).

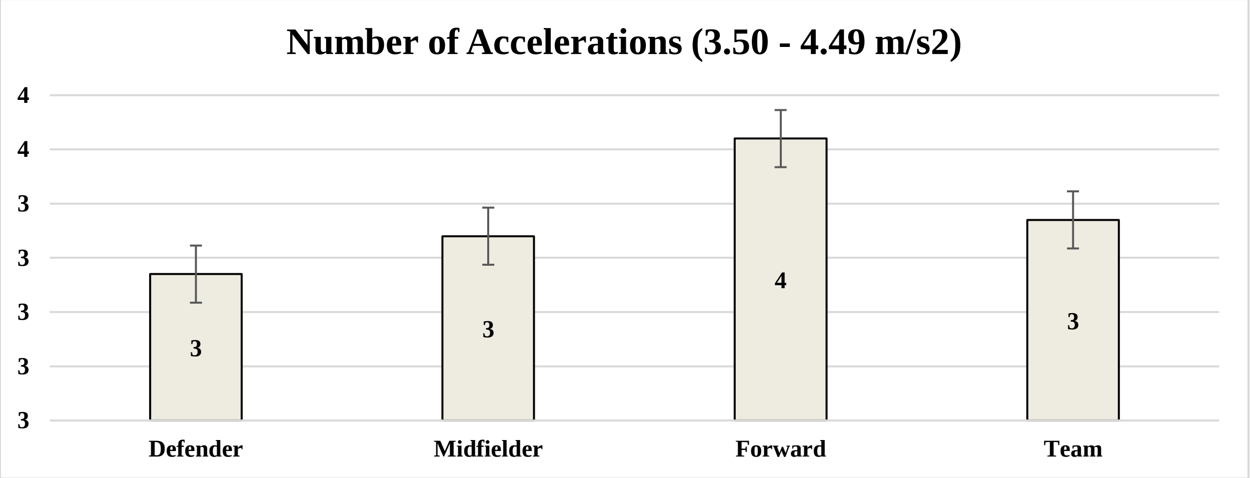

Figure 21. Comparison of differences in Number of Accelerations (3.50 – 4.49 m/s2) between position groups.

For Number of Accelerations (4.50 – 50.00 m/s2), Bonferroni's test revealed no significant differences between Positions (p = 0.77 – 0.85).

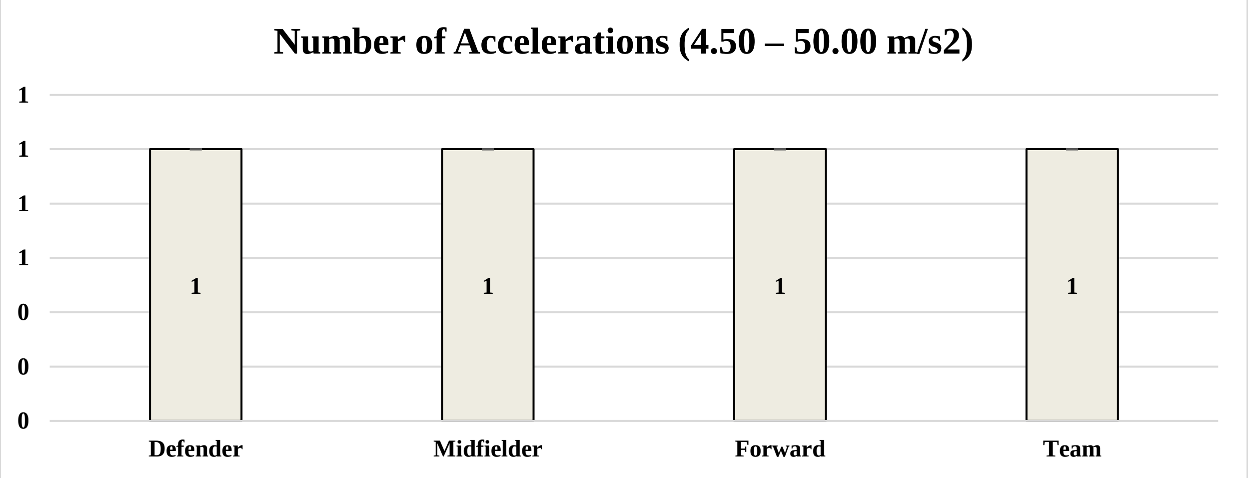

Figure 22. Comparison of differences in Number of Accelerations (4.50 – 50.00 m/s2) between position groups.

For Number of Decelerations (-4.49 – -3.50 m/s2), Bonferroni's test revealed significant differences between Forwards and all other Positions (p = 0.000).

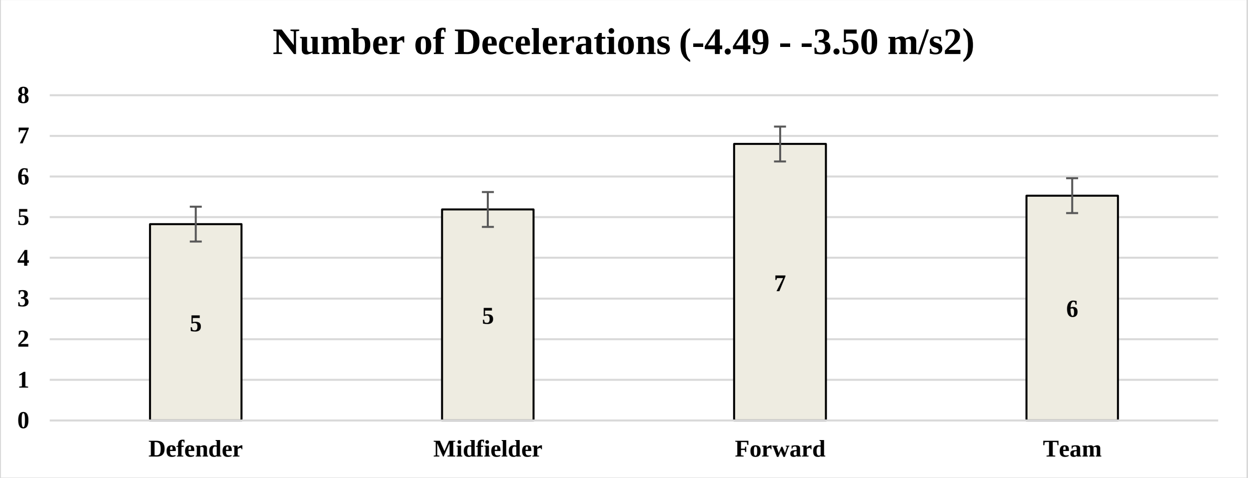

Figure 23. Comparison of differences in Number of Accelerations (-4.49 - -3.50 m/s2) between position groups.

For Number of Decelerations (-4.49 – -3.50 m/s2), Bonferroni's test revealed no significant differences between Positions (p = 0.093 - 1.000).

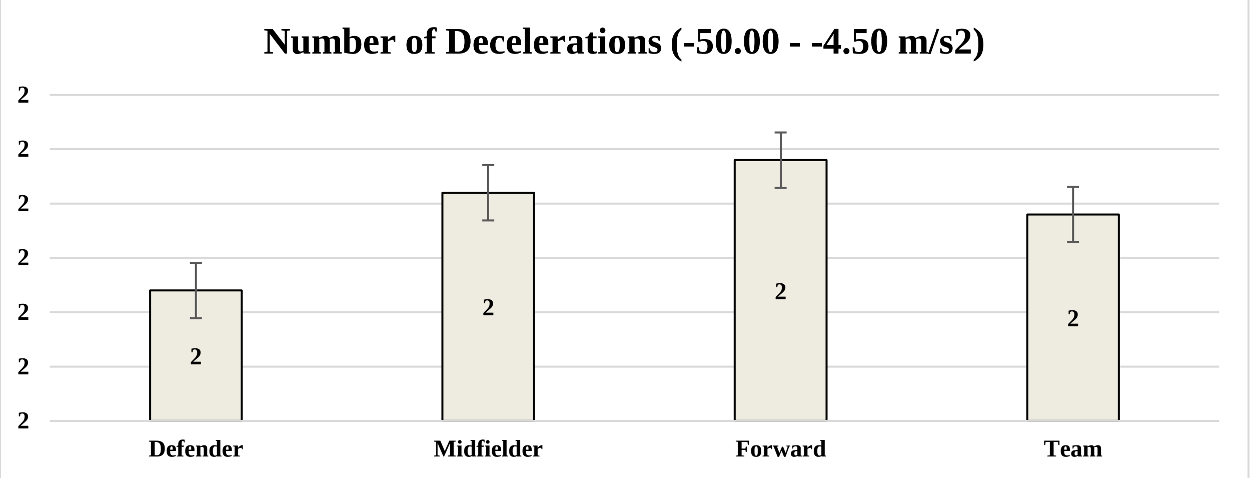

Figure 24. Comparison of differences in Number of Accelerations (-50.00 - -4.50 m/s2) between position groups.

4.5 Effects of Season Phase on Internal Loads

No significant Position x Season Phase interaction was observed for any measure of internal load (p > 0.05). However, main effects for Season Phase were observed for HR Max [%] (p = 0.006, ηp2 = 0.018) Time in HRZ_1 (p = 0.000, ηp2 = 0.035), HRZ_2 (p = 0.000, ηp2 = 0.039), HRZ_5 (p = 0.021, ηp2 = 0.015), Training Load (p = 0.000, ηp2 = 0.038), and Calories (p = 0.000, ηp2 = 0.066).

Table 7. Effects of Season Phase on Internal Loads Tests of Between-Subjects Effects

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Observed Power^x
Season Phase	HR avg [bpm]	554.460	4	138.615	1.845	.118	.009	.562
	HR max [bpm]	644.914	4	161.229	1.613	.169	.008	.499
	HR avg [%]	145.190	4	36.298	1.447	.217	.007	.452
	HR max [%]	397.282	4	99.320	3.639	.006	.018	.878
	HRZ_1 Duration	14913831.260	4	3728457.814	7.047	.000	.035	.995
	HRZ_2 Duration	9256660.810	4	2314165.203	8.030	.000	.039	.998
	HRZ_3 Duration	145954.715	4	36488.679	.096	.984	.000	.070
	HRZ_4 Duration	2046732.269	4	511683.067	.709	.586	.004	.231
	HRZ_5 Duration	11411529.900	4	2852882.474	2.894	.021	.015	.783
	Training Load	125464.668	4	31366.167	7.634	.000	.038	.997
	Calories [kcal]	3561559.842	4	890389.961	13.768	.000	.066	1.000

For HR Average [bpm], Bonferroni's test revealed no significant differences between Season Phases (p = 0.070 – 1.000).

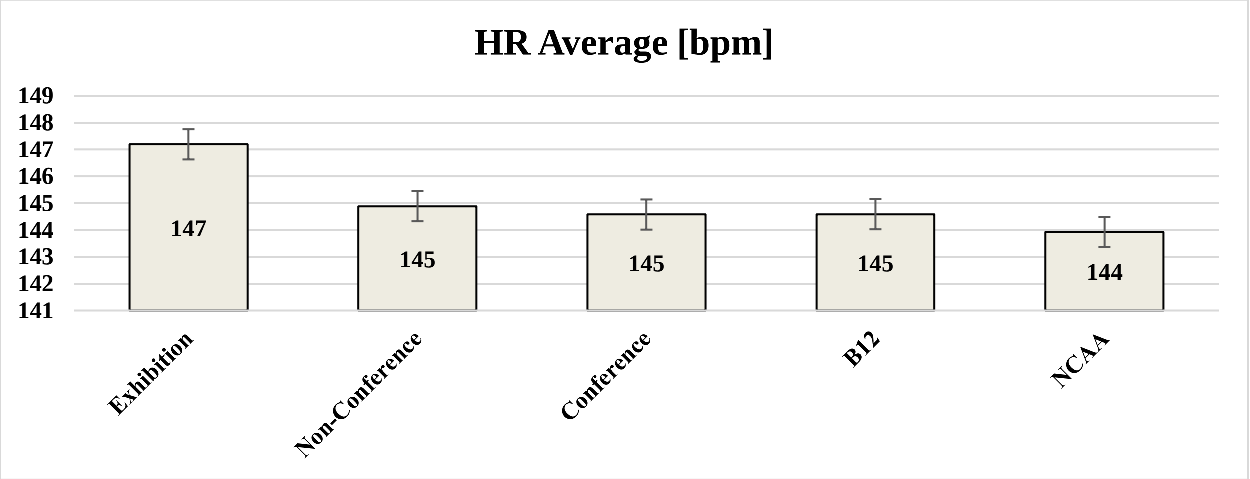

Figure 25. Comparison of differences in HR Average [bpm] between season phases.

For HR Average [bpm], Bonferroni's test revealed no significant differences between Season Phases (p = 0.162 – 1.000).

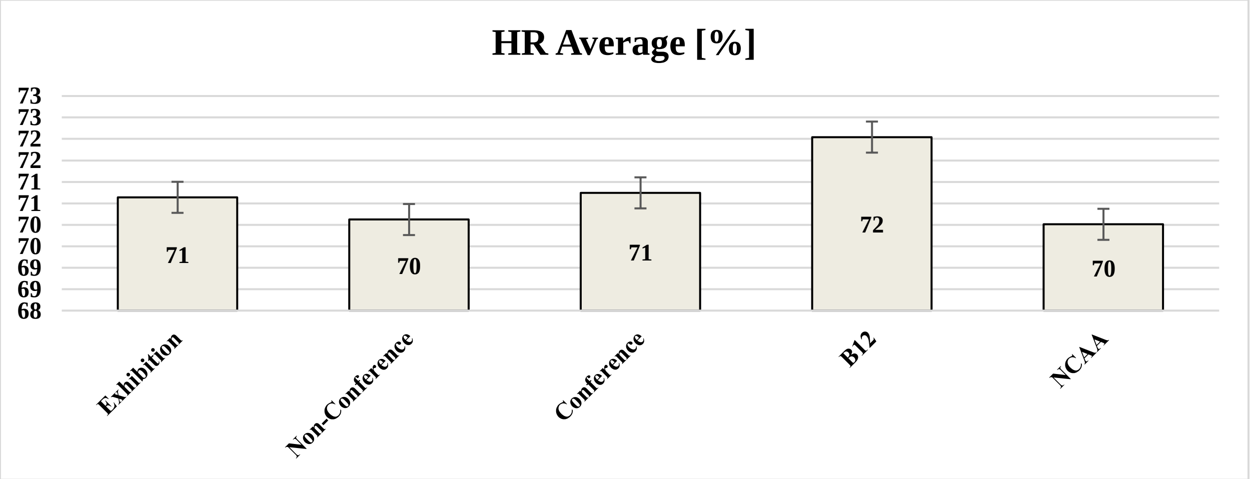

Figure 26. Comparison of differences in HR Average [%] between season phases.

For HR Maximum [bpm], Bonferroni’s test revealed no significant differences between Season Phases (p = 0.103 – 1.000).

Figure 27. Comparison of differences in HR Maximum [bpm] between season phases.

For HR Maximum [%], Bonferroni’s test revealed significant differences between Non-Conference and Conference Season Phases (p = 0.017).

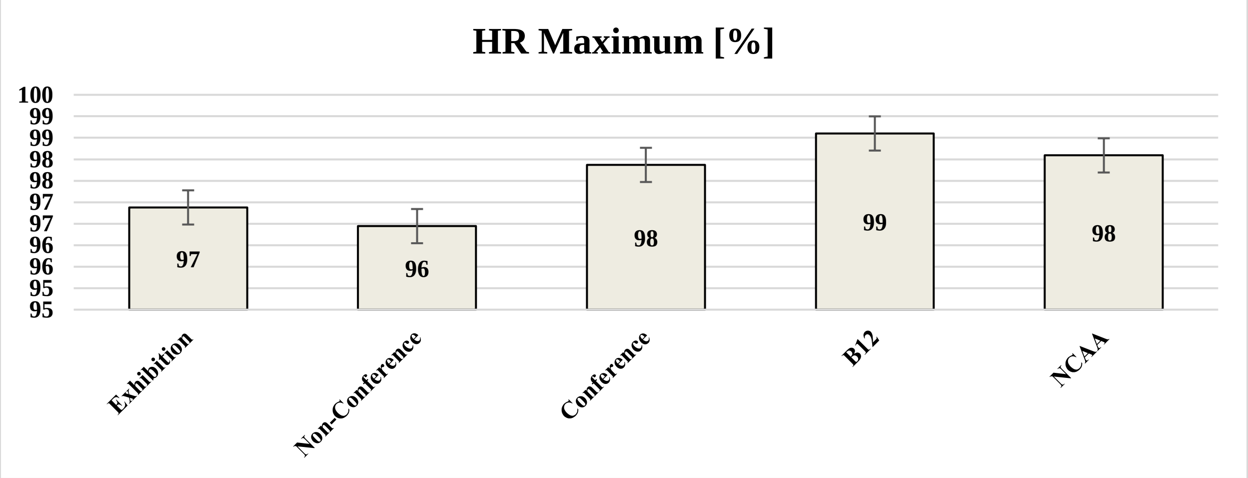

Figure 28. Comparison of differences in HR Maximum [%] between season phases.

For HR Zone 1 Duration, Bonferroni's test revealed significant differences between Exhibition and Non-Conference (p = 0.001), Conference (p = 0.002), and NCAA Season Phases (p = 0.000). Additional significant differences were observed between B12 and Non-Conference (p = 0.035), Conference (p = 0.042) NCAA Season Phases (p = 0.003).

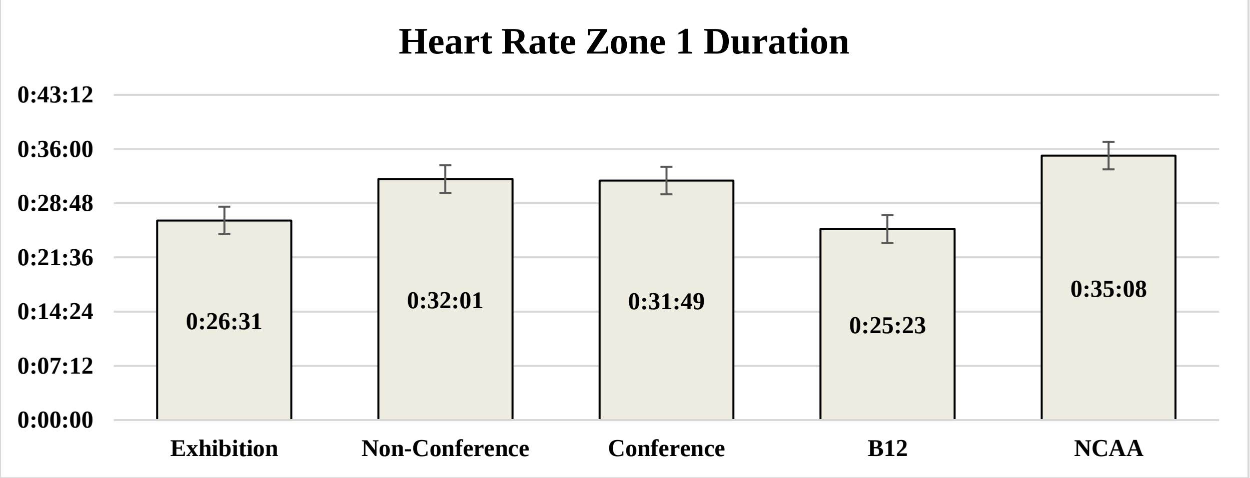

Figure 29. Comparison of differences in Heart Rate Zone 1 Duration between season phases.

For HR Zone 2 Duration, Bonferroni's test revealed significant differences between Exhibition Non-Conference (p = 0.000), Conference (p = 0.000), and NCAA Season Phases (p = 0.001).

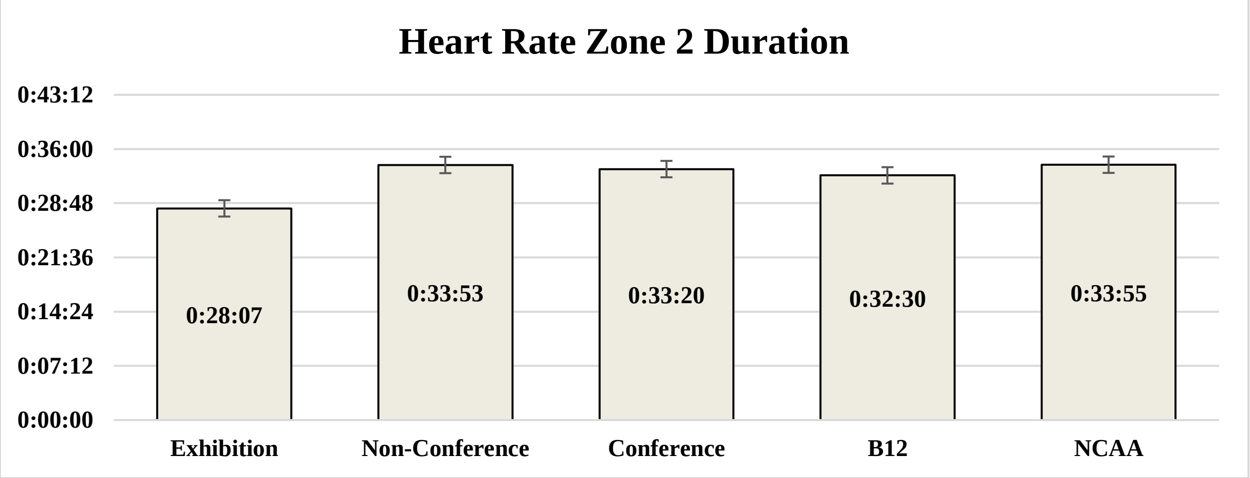

Figure 30. Comparison of differences in Heart Rate Zone 2 Duration between season phases.

For HR Zone 3 Duration, Bonferroni's test revealed no significant differences between Season Phases (p = 1.000).

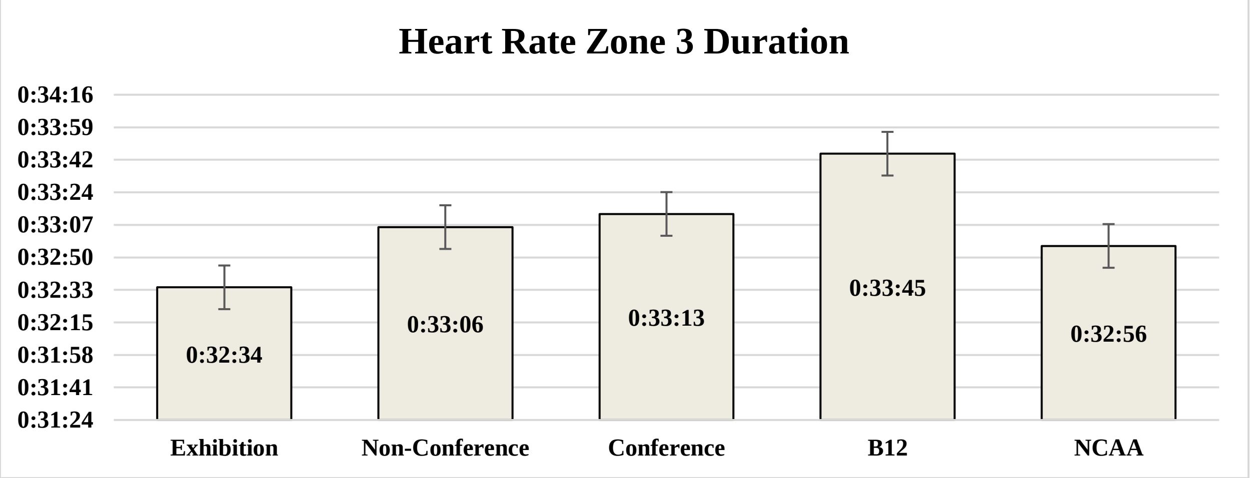

Figure 31. Comparison of differences in Heart Rate Zone 3 Duration between season phases.

For HR Zone 4 Duration, Bonferroni's test revealed no significant differences between Season Phases (p = 1.000).

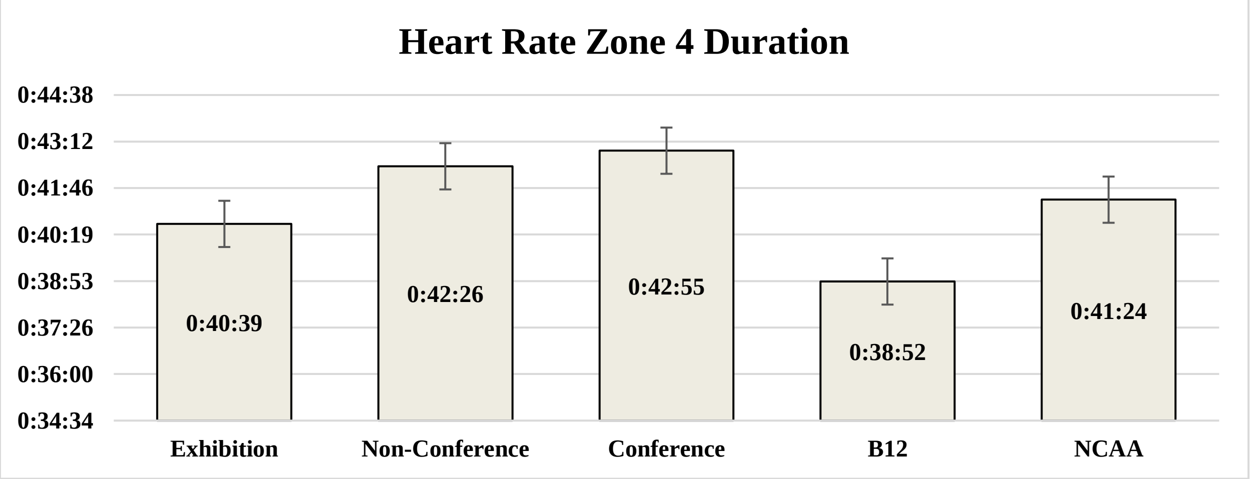

Figure 32. Comparison of differences in Heart Rate Zone 4 Duration between season phases.

For HR Zone 5 Duration, Bonferroni’s test revealed no significant differences between Season Phases (p = 0.057 – 1.000).

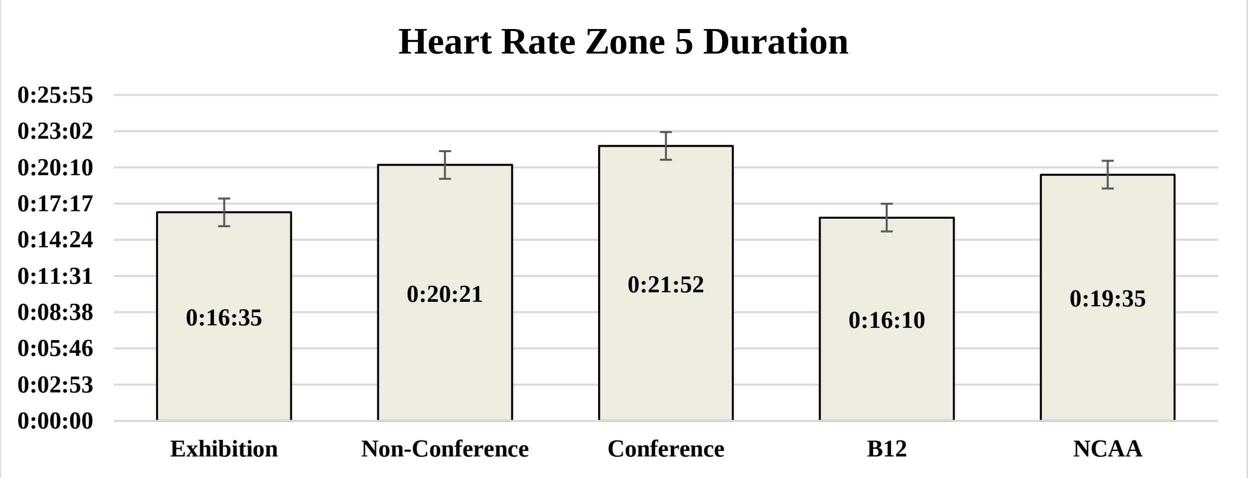

Figure 33. Comparison of differences in Heart Rate Zone 5 Duration between season phases.

For Training Load, Bonferroni’s test revealed significant differences between Exhibition and Conference Season Phases (p = 0.002). Additional significant differences were observed between B12 and Non-Conference (p = 0.041), Conference (p = 0.000), and NCAA Season Phases (p = 0.007).

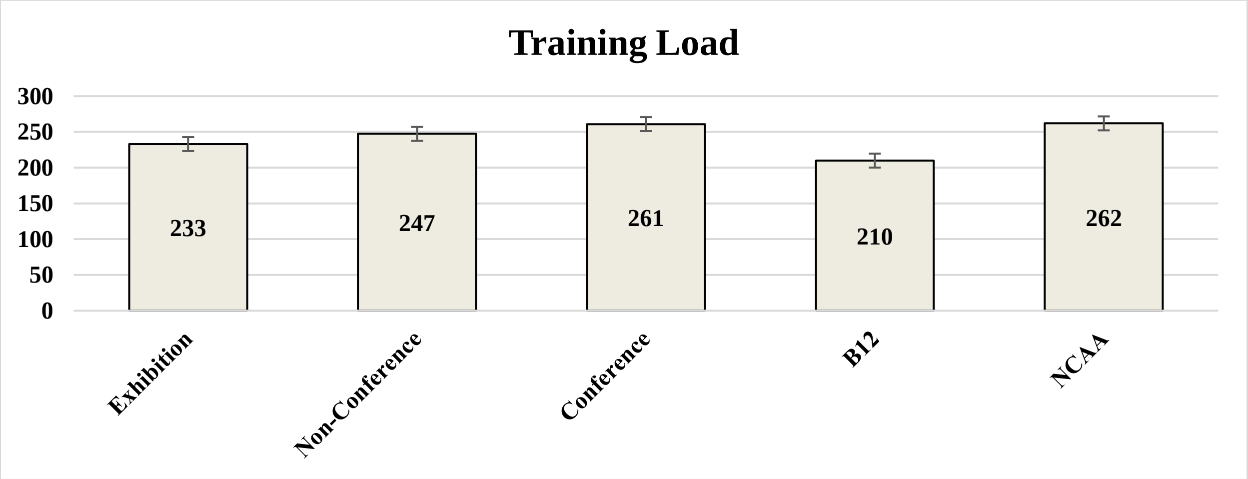

Figure 34. Comparison of differences in Training Load between season phases.

For Calories, Bonferroni’s test revealed significant differences between Exhibition and Non-Conference (p = 0.000), Conference (p = 0.000), and NCAA (p = 0.000) Season Phases. Additional significant differences were observed between Non-Conference and Conference Season Phases (p = 0.041).

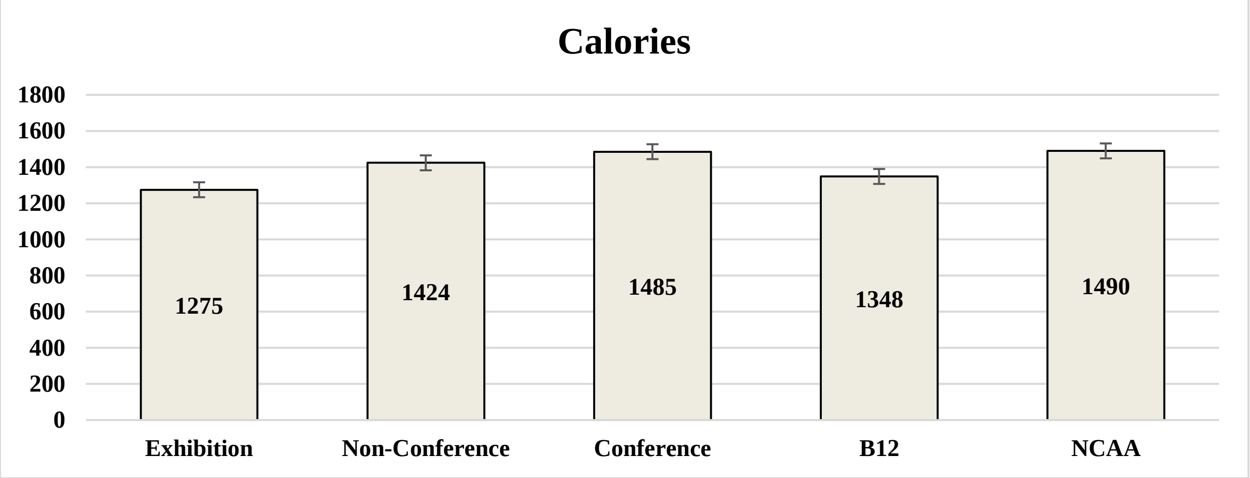

Figure 35. Comparison of differences in Calories burned between season phases.

4.6 Effects of Season Phase on External Loads

No significant Position x Season Phase interaction was observed for any measure of external load ($p > 0.05$). However, main effects for Season Phase were observed for Total distance [yd] ($p = 0.000$, ηp2 = .062), Sprints ($p = 0.000$, ηp2 = 0.027), Distance in Speed Zone 1 ($p = 0.000$, ηp2 = 0.043), 2 ($p = 0.000$, ηp2 = 0.030), 3 ($p = 0.000$, ηp2 = 0.041), 4 ($p = 0.000$, ηp2 = 0.035), 5 ($p = 0.003$, ηp2 = 0.020), Number of decelerations (-50.00 - -4.50 m/s²) ($p = 0.009$, ηp2 = 0.017).

Table 8. Effects of Season Phase on External Loads Tests of Between-Subjects Effects

Tests of Between-Subjects Effects								
Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Observed Power
Season Phase	Total distance [yd]	296520644.100	4	74130161.030	12.846	.000	.062	1.000
	Sprints	7080.298	4	1770.074	5.506	.000	.027	.977
	Distance in SZ1	13209009.660	4	3302252.416	8.872	.000	.043	.999
	Distance in SZ2	12401489.000	4	3100372.249	6.037	.000	.030	.986
	Distance in SZ3	19906055.230	4	4976513.807	8.394	.000	.041	.999
	Distance in SZ4	1354806.020	4	338701.505	7.113	.000	.035	.995
	Distance in SZ5	1479486.894	4	369871.723	3.997	.003	.020	.910
	Number of accelerations (-50.00 - -4.50 m/s²)	4.353	4	1.088	3.427	.009	.017	13.709
	Number of accelerations (-4.49 - -3.50 m/s²)	64.394	4	16.099	2.070	.083	.010	8.281
	Number of accelerations (3.50 - 4.49 m/s²)	19.009	4	4.752	1.852	.117	.009	7.408
	Number of accelerations (4.50 - 50.00 m/s²)	.000	4	.000	.	.	.	.

For Total Distance, Bonferroni's test revealed significant differences between B12 and all Season Phases (p = 0.000 – 0.027). Additional significant differences were observed between Exhibition and Conference (p = 0.000), B12 (p = 0.027), and NCAA (p = 0.039) Season Phases.

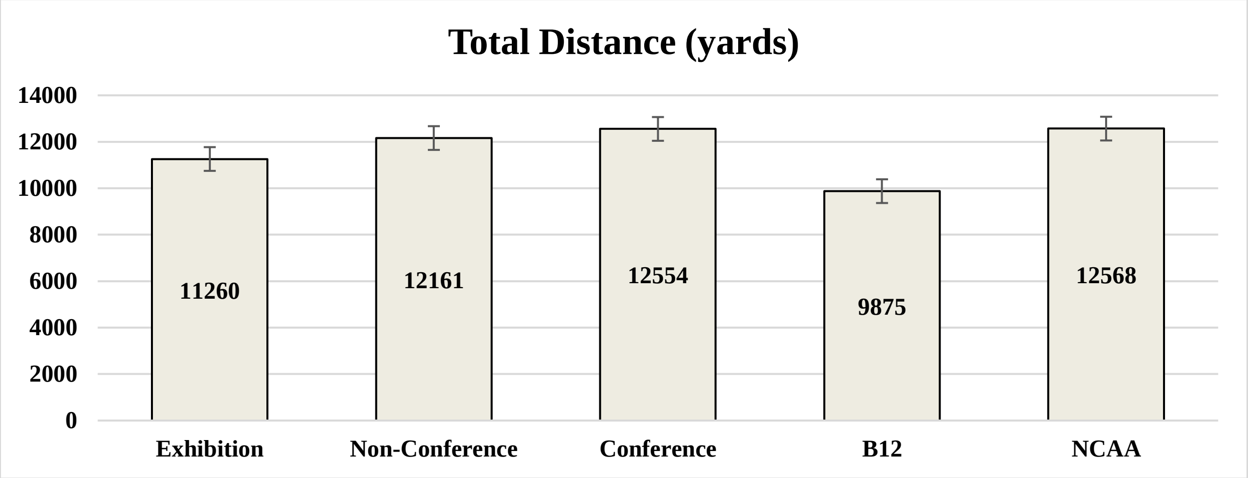

Figure 36. Comparison of differences in Total Distance (yards) between season phases.

For Sprints, Bonferroni's test revealed significant differences between Conference and Exhibition (p = 0.014) and B12 Season Phases (p = 0.007). Additional significant differences were observed between B12 and NCAA Season Phases (p = 0.013).

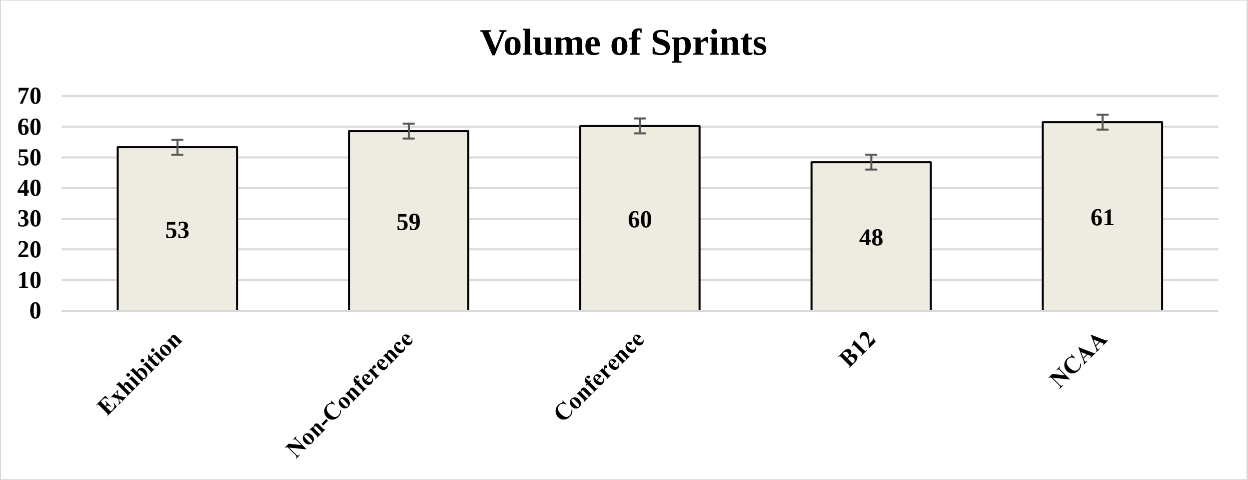

Figure 37. Comparison of differences in Sprints between season phases.

For Speed Zone 1 Distance, Bonferroni's test revealed significant differences between Exhibition, Non-Conference (p = 0.001), and Conference (p = 0.001) Season Phases. B12 and Non-Conference (p = 0.000), Conference (p = 0.000), and NCAA (0.005) Season Phases.

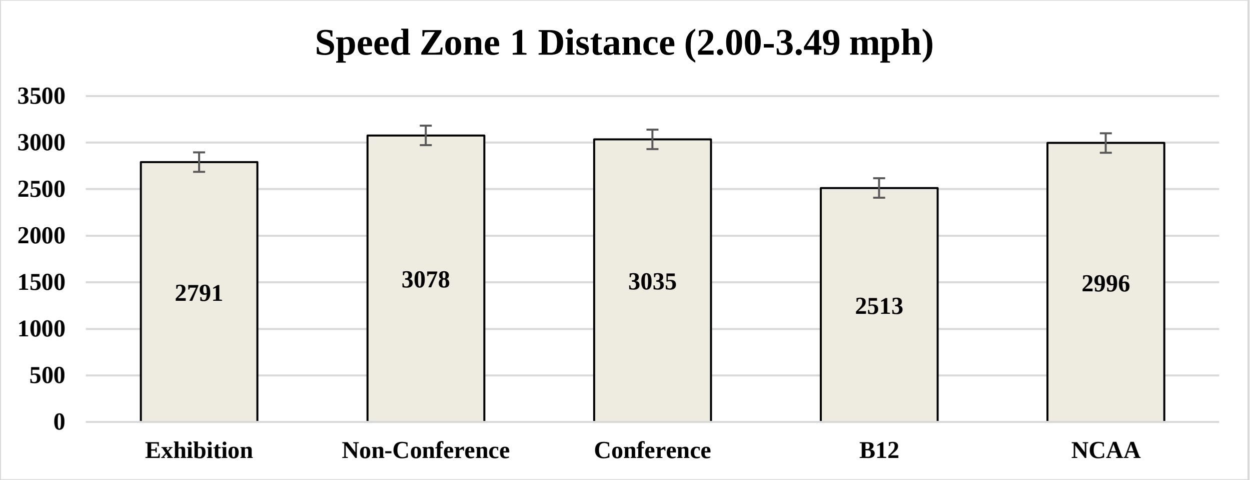

Figure 38. Comparison of differences in Speed Zone 1 Distance (2.00-3.49 mph) between season phases.

For Speed Zone 2 Distance, Bonferroni's test revealed significant differences between B12, Non-Conference (p = 0.005), Conference (p = 0.000), and NCAA Season Phases (p = 0.005)

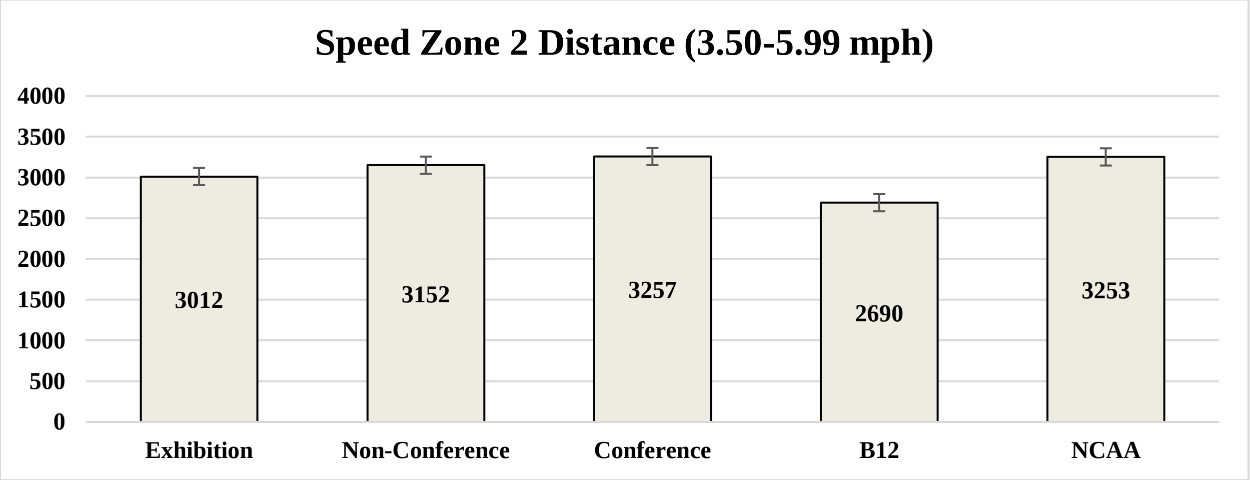

Figure 39. Comparison of differences in Speed Zone 2 Distance (3.50-5.99 mph) between season phases.

For Speed Zone 3 Distance, Bonferroni's test revealed significant differences between Conference, Exhibition (p = 0.002) and B12 Season Phases (p = 0.000). B12, Non-Conference (p = 0.000) and NCAA Season Phases (p = 0.005).

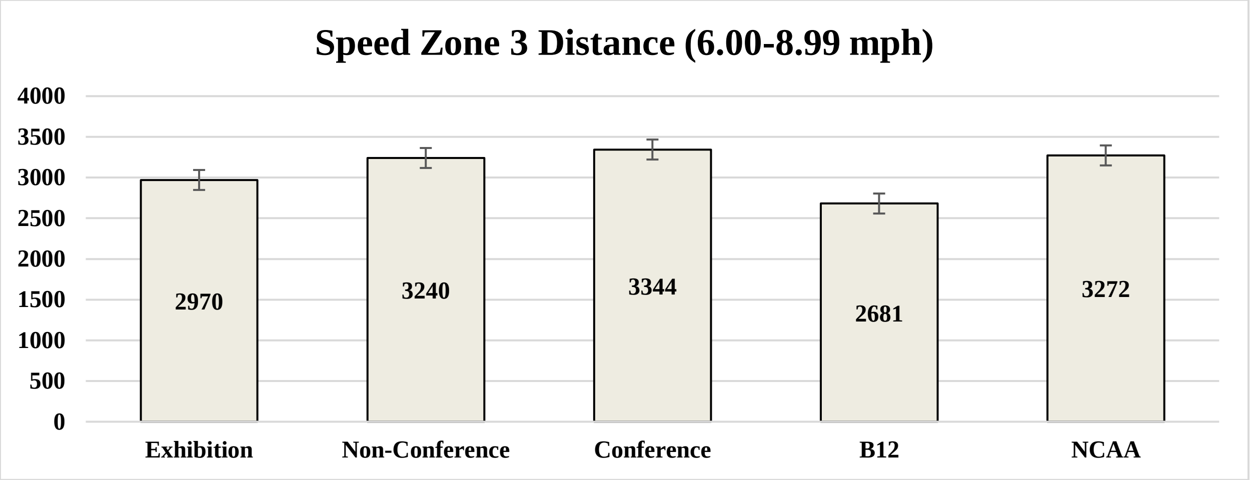

Figure 40. Comparison of differences in Speed Zone 3 Distance (6.00-8.99 mph) between season phases.

For Speed Zone 4 Distance, Bonferroni's test revealed significant differences between Conference, Exhibition (p = 0.000), Non-Conference (p = 0.026), and B12 Season Phases (p = 0.014).

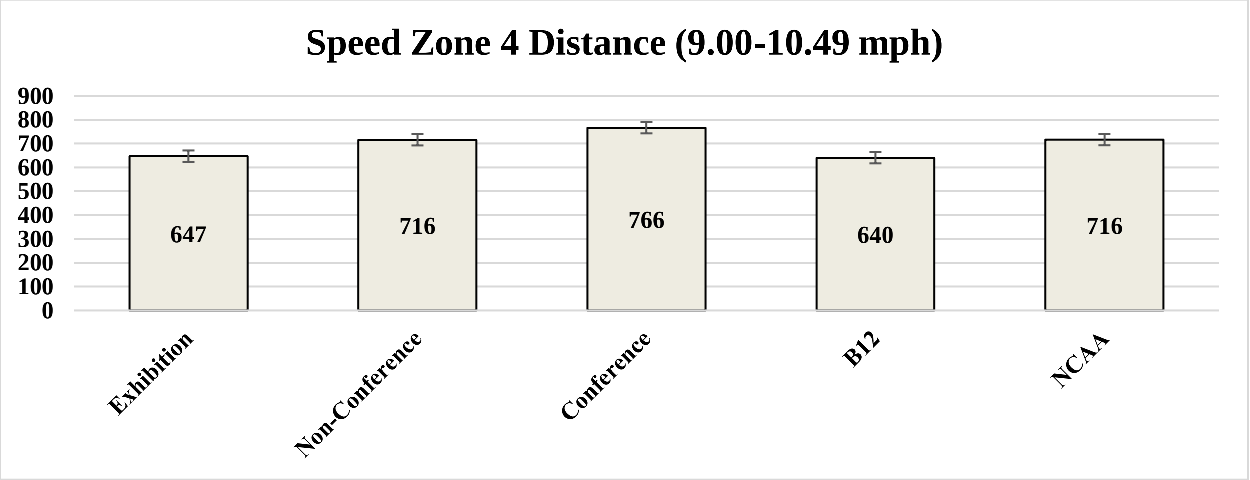

Figure 41. Comparison of differences in Speed Zone 4 Distance (9.00-10.49 mph) between season phases.

For Speed Zone 5 Distance, Bonferroni's test revealed significant differences between Exhibition, Conference (p = 0.002) and NCAA Season Phases (p = 0.029).

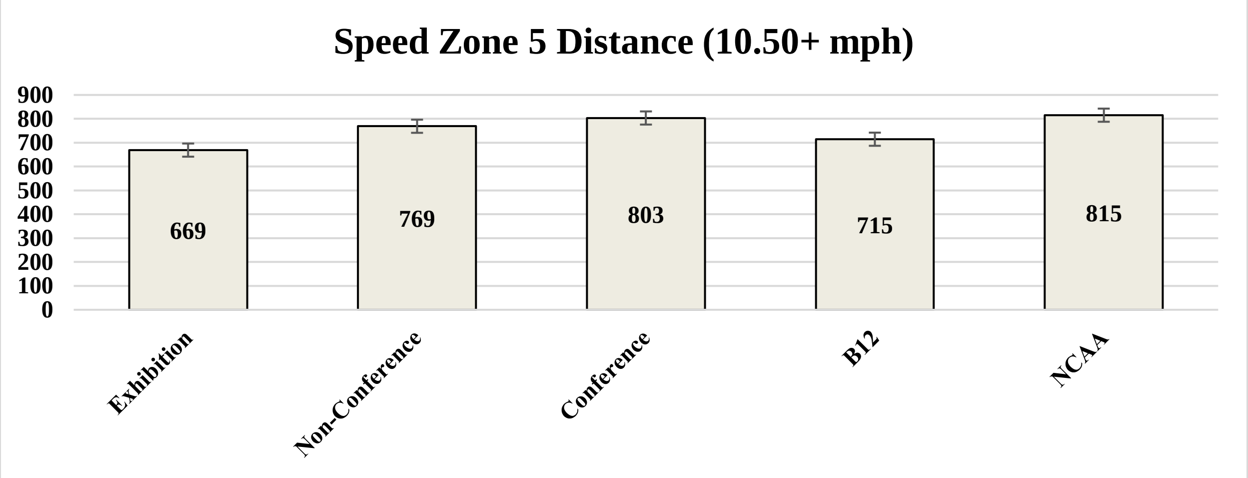

Figure 42. Comparison of differences in Speed Zone 2 Distance (10.50+ mph) between season phases.

For Number of Decelerations (3.50 - 4.49 m/s2), Bonferroni's test revealed significant differences between Exhibition and Non-Conference (p = 0.04), Conference (p = 0.04), and NCAA (p = 0.03) Season Phases.

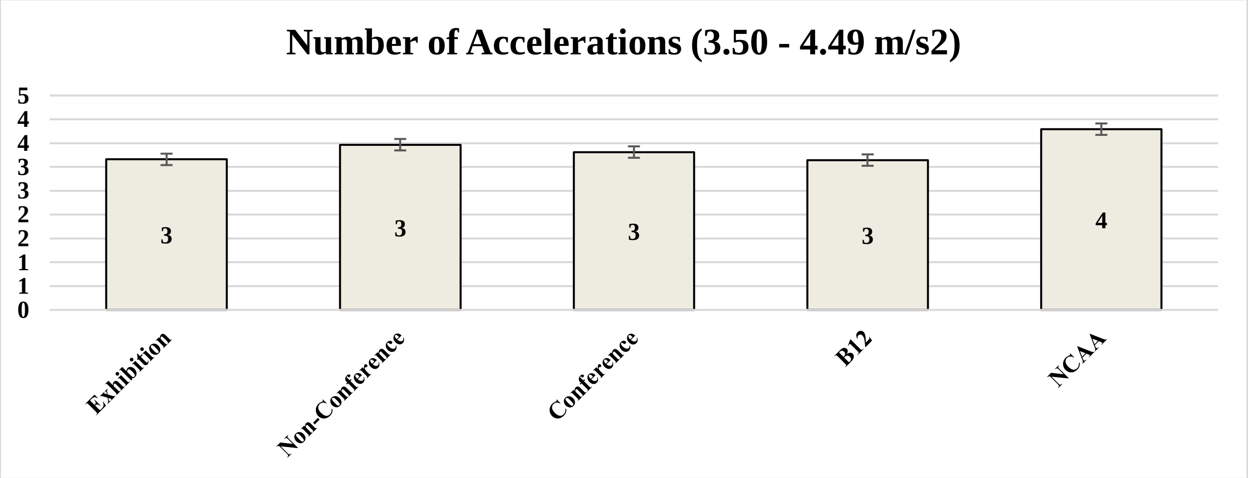

Figure 43. Comparison of differences in Number of Decelerations (3.50 - 4.49 m/s2) between season phases.

For Number of Decelerations (4.50 - 50.00 m/s2), Bonferroni's test revealed significant differences between Exhibition and Non-Conference (p = 0.04), Conference (p = 0.04), and NCAA (p = 0.03) Season Phases.

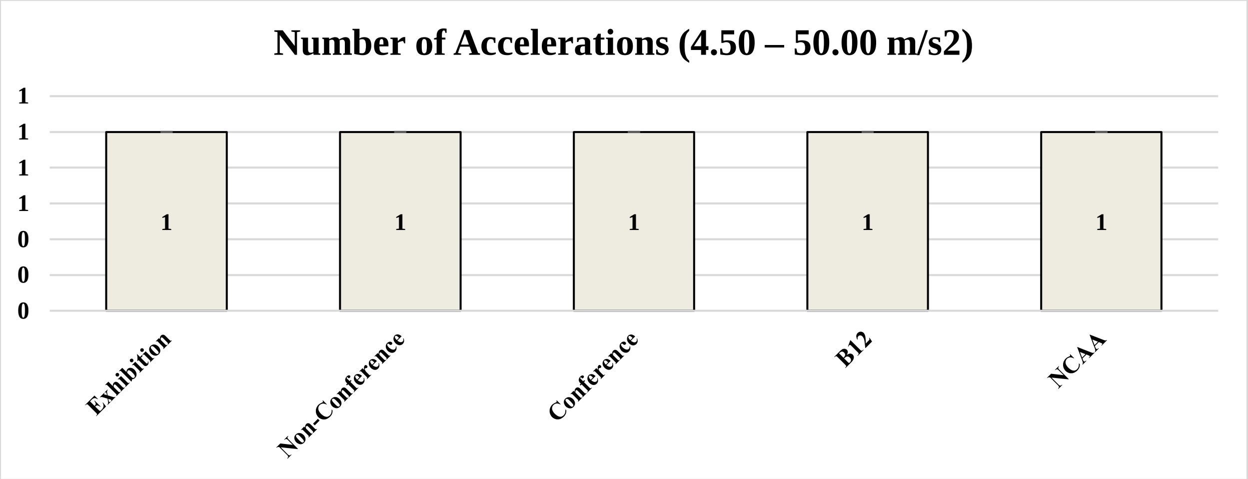

Figure 44. Comparison of differences in Number of Decelerations (4.50 - 50.00 m/s2) between season phases.

For Number of Decelerations (-4.49 - -3.50 m/s2), Bonferroni's test revealed no significant differences between Season Phases (p > 0.05).

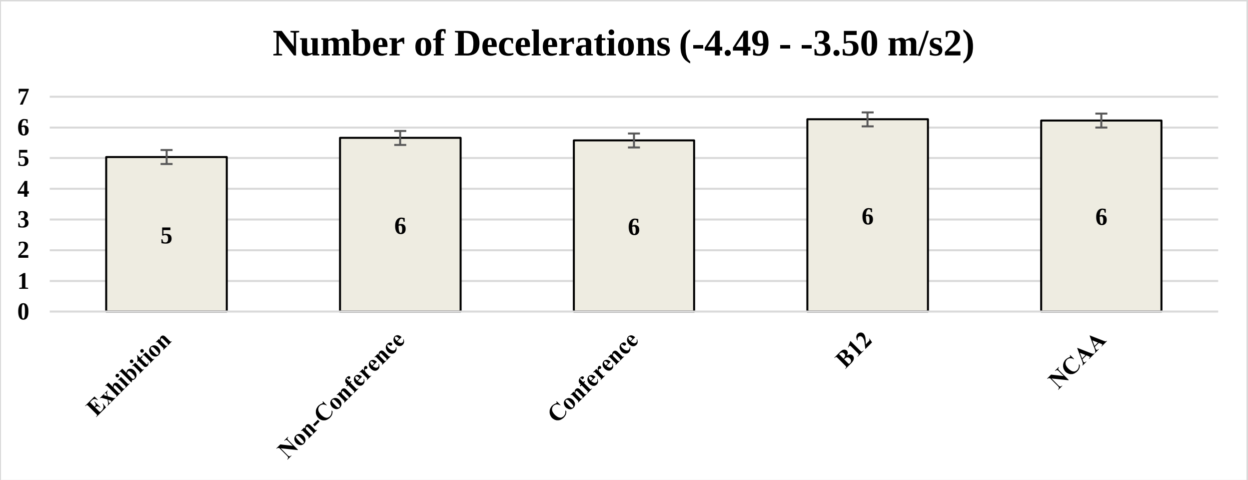

Figure 45. Comparison of differences in Number of Decelerations (-4.49 - -3.50 m/s2) between season phases.

For Number of Decelerations (-50.00 - -4.50 m/s2), Bonferroni’s test revealed significant differences between B12, Non-Conference (p = 0.030), Conference (p = 0.025) and NCAA Season Phases (p = 0.009).

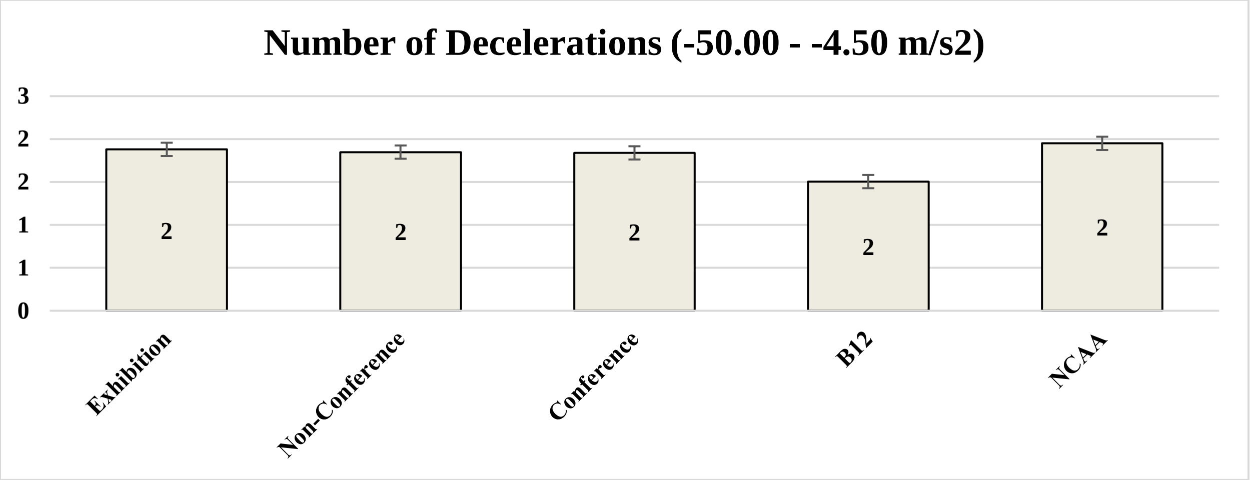

Figure 46. Comparison of differences in Number of Decelerations (-50.00 - -4.50 m/s2) between season phases.

CHAPTER V

CONCLUSION

The primary aim of this study was to examine differences in internal (ITLs) and external training loads (ETLs) between 5 phases of a NCAA Division I women's soccer season. Based on a generalized knowledge of sport-related demands, tactics and competition schedules, it was hypothesized that differences would exist between position and season phase ITLs and ETLs. To the best of the investigators knowledge, this is the first study to examine position and season phase-specific ITLs and ETLs, with such depth regarding physiological measures which contribute to athletic performance. The primary findings of the study demonstrated significant differences between position groups (ITL; HRavg [bpm and %], HRZ 1-5, Training Load, Calories Burned, ETL; Total Distance, Volume of Sprints, Speed Zone 1-5, Number of Decelerations (-4.49 - -3.50),) and season phases (ITL; HRmax%, HRZ 1-2, Training Load, Calories, ETL; Total Distance, Volume of Sprints, Speed Zone 1-5, Number of Decelerations (-50.00 - -4.50)). These findings may serve as a much needed reference for enhancing current approaches aimed at preparing female athletes for the demands of their competitive season.

5.1. Effects of Position and Season Phase Interactions on Internal and External Loads

No statistically significant interactions were observed between Position and Season Phase in the current study. However, there are several plausible explanations for this observation, many of which are based in understanding the aim of the two-way MANOVA and its limitations. It is quite possible that the observed lack of interaction between Position and Season Phase on all of the dependent variables (collectively) may not necessarily mean that there is no significant effect at all, but instead, the joint effects are not statistically higher than the sum of both effects individually. This means that for certain measures of ETL or ITL, Position or Season Phase's individual effect sizes may be larger than when the two variables interact with one another.

Although no statistically significant interactions were observed, these findings can still be useful to coaches, researchers, and athletes alike who are interested in further understanding the effect specific independent variables, such as position or season phase, have on ETL and ITL throughout the course of the season within the collegiate women's soccer population.

5.2. Effects of Position on Internal Loads

The current study observed significant differences in ITLs based on Position. These findings are consistent with previous research (Martínez-Lagunas et al. 2014; Krustrup et al. 2005) conducted in senior elite female soccer populations. Within the current study, differences were observed between positions for the following measures: HRavg [bpm], HRavg [%], HRZ1-5 durations, Training Load, and Calories Burned. The results of this study revealed that Defenders HRavg [bpm & %] demonstrated significantly higher ITLs than any other position, while TLs for Midfielder's HRavg [bpm] were significantly higher than Forwards. Analyses regarding HRZ durations revealed significant differences in HRZ1-5 durations between all positions. These findings highlight the unique demands of each position within women's collegiate soccer.

Although general approaches are typically taken to develop and maintain cardiorespiratory fitness within the collegiate women's soccer athlete population, the findings of the current study provide support for implementing individualized (position-specific) approaches especially as it relates to adequately preparing athletes for the demands of their sport and positively contributing to their development.

An interesting finding regarding Training Load and Calories Burned were the significant differences between Defenders and all other positions. Training Load is the standard Polar Team Pro metric which assesses an event's intensity. While Midfielders and Forwards experience similar intensities during games occurring at any phase of the season, intensities for the Defender are significantly higher throughout. Furthermore, Defenders also expend (or burn) significantly more calories than any other position on the pitch during games. These findings provide further support for properly preparing athletes for the demands of their sport and position (especially if athletes will be expected to play multiple positions) and ensuring that the athletes have access to nutritional options that provide them with enough energy to compete at the highest level possible.

Based on the results of the current study, special consideration should be given to preparing the women's collegiate soccer athlete for the position-specific internal demands of their sport. This is true from many perspectives, but especially as it relates to the sport coach, strength and conditioning specialist, and athletic trainer. Observations from the current study can be utilized to develop a framework which enhances the understanding of positional demands, approaches for preparing athletes to meet those demands, and identifying which athletes possess the qualities to succeed at certain playing positions.

5.3. Effects of Position on External Loads

The current study observed significant differences in external loads based on Position. Specifically, differences were observed between positions for Total Distance, Sprint Volume, Speed Zones 1-5, and Number of Decelerations (-4.4.49 - -3.50). These findings are consistent with previous research (Alexander et al. 2014; Andrzejewski et al. 2016; Clarke et al. 2018; Datson et al. 2017; Martínez-Lagunas et al. 2014; Sausaman et al. 2019) conducted within elite soccer athlete populations. The results of this study revealed that Midfielders cover significantly more distance than Forwards, but no significant differences exist between Defenders and any other position. Furthermore, significant differences in sprint volume exist between all positions with Defenders performing the fewest sprints and Forwards performing the most sprints. While these findings highlight the similarities and differences between positions and unique characteristics of each position, they can also be utilized to better identify general and specific potential limiters to performance.

The results from the present study show that distances covered at specific intensities and the number of intense accelerations and decelerations significantly differed by position. To the authors knowledge, these findings are novel for the women's collegiate soccer athlete. Defenders cover significantly more distance in Speed Zone 1 (2.00 – 3.49 mph) than any other position, Midfielders cover significantly more distance in Speed Zones 2-3 (3.50 – 8.99 mph) than any other position, and Forwards cover significantly more distance in Speed Zones (9.00 – 10.50+ mph). Additionally, Forwards perform significantly more intense decelerations than any other position group (-4.49 – -3.50 m/s^2). Altogether, these findings are of utmost importance as they are a direct reflection of game demands. While it is apparent that each position is unique in its own right, these findings can provide valuable information for sport coaches, strength and conditioning professionals, and the athletic training staff. For the sport coach, these findings may be useful in designing training sessions, selecting starting lineups, game tactics and developing a longitudinal plan for athletic development. For the strength and conditioning professional, these findings may be useful in the design of conditioning sessions that are meant to prepare the athlete to cover distances at specific intensities multiple times within a game and over the course of a season or multiple seasons. For the athletic trainer, this information may be useful for identifying position-specific risks for injury and the mechanisms that may contribute to those injuries.

5.4. Effects of Season Phase on Internal Loads

The current study observed significant differences in internal loads based on Season Phase. Specifically, differences were observed between Season Phases for HR Max [%], HRZ1 and HRZ2, Training Load, and Calories. Although these findings are supported by previous research conducted within similar populations, this study is the first to examine differences between season phases within the women's collegiate soccer population (Anderson et al. 2016; Esco et al. 2014; Jeong et al. 2011; Malone et al. 2015; Oliveira et al. 2019). The results of this study revealed that HRmax [%] was significantly higher during Non-Conference games when compared to Conference games. Furthermore, time spent in HRZ_1 during the Exhibition and B12 phases were significantly greater than the Non-Conference, Conference, and NCAA phases. Additionally, time spent in HRZ_2 during the Exhibition phase was significantly greater than any other phase of the season. Although these findings are likely contextual and dependent on several contributing factors, this information provides the framework for better understanding season phase-specific characteristics of cardiorespiratory functioning within the women's college soccer athlete population.

It should be noted that significant differences also exist in training load and calories burned between season phases as well. Specifically, the results of this study observed significantly greater training loads during the Non-Conference season phase compared to the Exhibition season phase. Beyond the Non-Conference season phase training loads do not significantly differ except for the B12 phase which is less demanding than all season phases except for the Exhibition phase. In regards to calories burned, this study observed significantly fewer calories burned during the Exhibition phase as compared to any other phase except for the B12 phase. Additionally, significantly more calories are burned during the Conference as compared Non-Conference phase. Overall, these findings provide evidence of the significantly different physical demands throughout specific phases of the NCAA Division I women's college soccer season. This information can be useful for identifying periods of the season where the demands are the highest and lowest, how these changes may affect the athlete and their performance, and possible interventions that can be implemented to optimize performance.

5.5. Effects of Season Phase on External Loads

The current study observed significant differences in external loads based on Season Phase. Specifically, significant differences were observed for Total Distances, Volume of Sprints, Speed Zones 1-5, and Number of Decelerations (-50.00 - -4.50). These findings agree with those reported in previous research, but also provide more insight as it relates to the women's collegiate soccer athlete population (Malone et al. 2015; Morgans et al. 2014; Oliveira et al. 2019). As it relates to the sample examined within the current study, total distance covered during the Conference and NCAA phases of the season are significantly greater than any other phase. Distance covered in Speed Zone 1 and 2 during the Non-Conference, Conference, and NCAA phases of the season are significantly greater than any other. Distance covered in Speed Zone 3 during the Conference phase of the season is significantly greater than Exhibition and B12 season phases. Distance covered in Speed Zone 4 during the Conference phase of the season is significantly greater than all other season phases, except for the Exhibition phase. Distance covered in Speed Zone 5 during the Conference and NCAA phase of the season are significantly greater than that which is covered during the Exhibition phase.

To the author's knowledge, this is the first study to report these findings with such great depth. That is, no other study to date has assessed 80 games over the course of four seasons within the NCAA Division I women's college soccer population to better understand the demands of specific phases. Although these findings contribute to a more in-depth understanding, they also draw attention toward phases of the season that are before and/or after those that are more demanding. This information can be useful for further understanding the unique characteristics of each phase of the season and identifying potential times where athletes may be over- or underprepared for the demands of their sport. The authors recommend that coaching staff with the capacity to conduct similar analyses do so in order to better understand how they can identify areas of concern and appropriate interventions while accommodating for the specific demands that their team(s) may have to withstand.

5.6. Conclusions

The primary aim of this study was to examine differences in internal and external training loads between 5 phases of a NCAA Division I women's soccer season. To the best of our knowledge, this was the first investigation to examine the unique characteristics of both playing position and season phase within the collegiate women's soccer athlete population with such depth. Analyses conducted within this study were based on 797 individual data points from 116 athletes who participated in 80 games over the course of five competitive seasons. An important finding from this study were the significant differences in ITLs and ETLs between positions. These results are supported by previous research and can be partially explained by the demands of the game, but also by each athlete's (or position groups) physical attributes and capacities. Identifying these characteristics and understanding positional strengths and weaknesses could be utilized by practitioners in order to reduce injury risks, enhance performance, and better server their athletes all-around. Another important finding from this study were the significant differences in ITLs and ETLs between season phases. These results are novel, especially within the women's college soccer population. Of interest are the unique demands of each phase of the season, phases of the season which are significantly more or less demanding, and phases of the season which prelude or follow the most demanding phases of the season. For the practitioner, the ability to accurately quantify the demands of sport are particularly useful and can benefit many (if not all) aspects of the organization. Furthermore, the ability to accurately quantify the demands of specific phases of the competitive season can assist with making decisions in regards to training structure and scheduling, timing and focus of specific strength and conditioning approaches, and identifying best practices for enhancing recovery and readiness.

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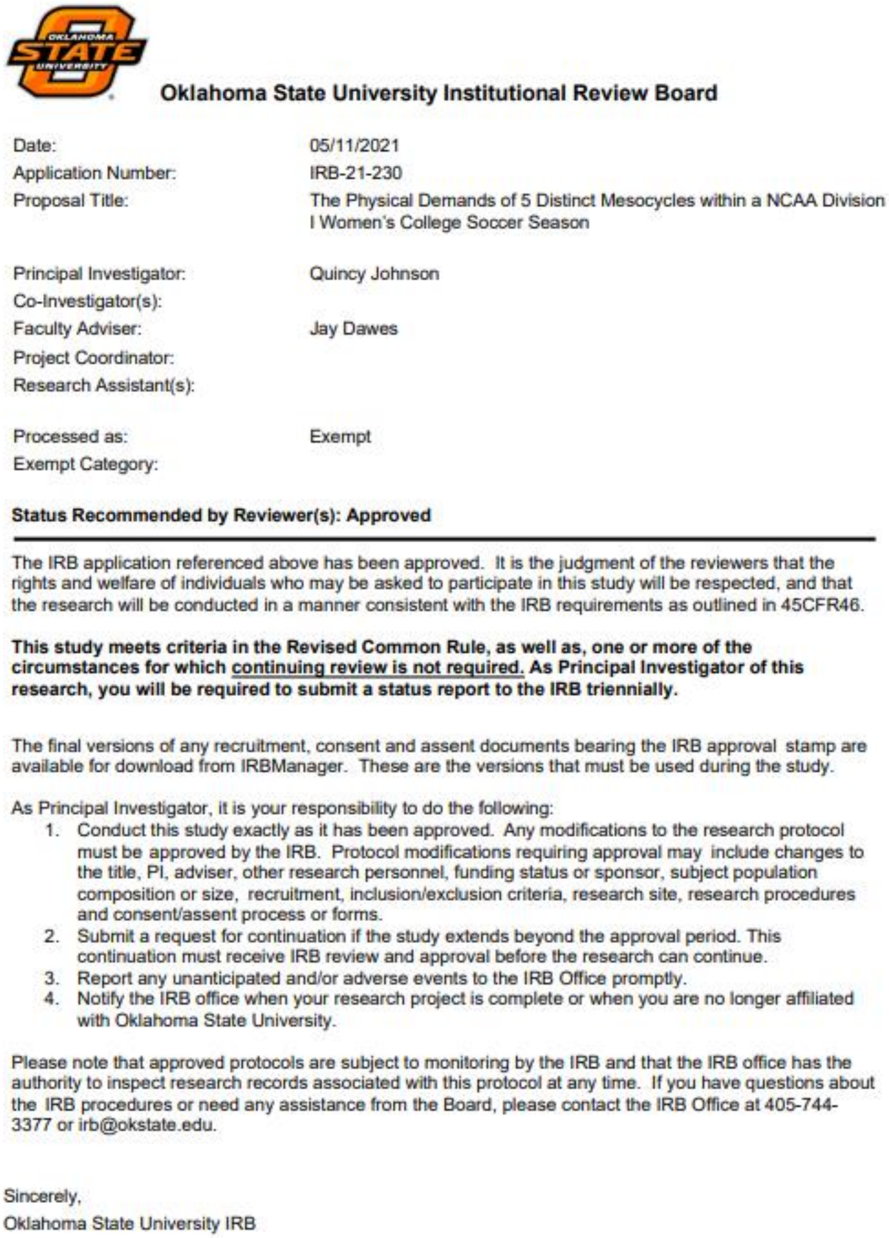
APPENDIX A: IRB APPROVAL LETTER



Oklahoma State University Institutional Review Board

Date:	05/11/2021
Application Number:	IRB-21-230
Proposal Title:	The Physical Demands of 5 Distinct Mesocycles within a NCAA Division I Women's College Soccer Season
Principal Investigator:	Quincy Johnson
Co-Investigator(s):	
Faculty Adviser:	Jay Dawes
Project Coordinator:	
Research Assistant(s):	
Processed as:	Exempt
Exempt Category:	

Status Recommended by Reviewer(s): Approved

The IRB application referenced above has been approved. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in 45CFR46.

This study meets criteria in the Revised Common Rule, as well as, one or more of the circumstances for which continuing review is not required. As Principal Investigator of this research, you will be required to submit a status report to the IRB triennially.

The final versions of any recruitment, consent and assent documents bearing the IRB approval stamp are available for download from IRBManager. These are the versions that must be used during the study.

As Principal Investigator, it is your responsibility to do the following:

1. Conduct this study exactly as it has been approved. Any modifications to the research protocol must be approved by the IRB. Protocol modifications requiring approval may include changes to the title, PI, adviser, other research personnel, funding status or sponsor, subject population composition or size, recruitment, inclusion/exclusion criteria, research site, research procedures and consent/assent process or forms.
2. Submit a request for continuation if the study extends beyond the approval period. This continuation must receive IRB review and approval before the research can continue.
3. Report any unanticipated and/or adverse events to the IRB Office promptly.
4. Notify the IRB office when your research project is complete or when you are no longer affiliated with Oklahoma State University.

Please note that approved protocols are subject to monitoring by the IRB and that the IRB office has the authority to inspect research records associated with this protocol at any time. If you have questions about the IRB procedures or need any assistance from the Board, please contact the IRB Office at 405-744-3377 or irb@okstate.edu.

Sincerely,
Oklahoma State University IRB

VITA

Quincy Rashad Johnson

Candidate for the Degree of

Doctor of Philosophy

Dissertation: THE PHYSICAL DEMANDS OF 5 DISTINCT MESOCYCLES WITHIN A NCAA DIVISION I WOMEN'S COLLEGE SOCCER SEASON

Major Field: Health, Leisure, and Human Performance

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Education:

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Experience:

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Professional Memberships:

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