EVALUATING THE PERCEPTION AND APPLICATIONS OF SPORTS SCIENCE TO NCAA SOCCER

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ABSTRACT

Nearly fifty thousand student-athletes compete for an NCAA Men's and Women's soccer program at the Division I, II, or III level. Many of these programs have began adopting sports science, or the application of scientific principle and technique, to optimize sports performance. It is unclear who is tasked with carrying this responsibility out at the NCAA level and how. The purpose of this dissertation is to examine these responsibilities and demonstrate application of sports science to NCAA men's and women's soccer.

The first study aims to evaluate the perceptions of sports science applications and the sports scientist role in NCAA soccer using an exploratory survey study design consisting of questions about demographics, program capabilities and practices of training load monitoring, training and practice planning, and training load monitoring feedback. Respondents (n = 187) consisted of sport coaches (n = 128), strength and conditioning coaches (n = 45) and sports scientists (n = 13). Traning load monitoring tools most commonly included questionnaires and session rating of perceived exertion (sRPE). The head coach was identified to most typically be responsible for training planning. To communicate training load information throughout a program, verbal, informal communication (62.6%) was the most commonly employed communication channel. Future resources and trainings about training load monitoring and management may be most beneficial if directed towards coaches provided their responsibilities in managing training loads at the NCAA level.

Study two considered how training loads are managed within a program and is intended to identify the distribution of training loads throughout the in-season NCAA men's and women's soccer microcycle. Soccer field players from an NCAA Division I program wore GPS and accelerometer monitors throughout the Fall 2021 season for all training sessions and matches.

Players were categorized into bench, substitute, and starter while days throughout each microcycle were classified according to the number of days before match day. Linear mixed effect models were used to examine the effects of player role and day of microcycle on external training loads. Match day elicited the greatest training loads during the microcycle. The day prior to the match (MD-1) elicited the lowest. Starters accumulated the greatest training loads for all measures except total sprint distance. Total playerload and medium- and high-intensity accelerations and decelerations were significantly greater amongst the men compared to the women. Provided that most training load is developed on match day by starters, presenting substitutes and bench players with supplemental training load could better prepare these players for starter match demands.

The final study measured physical performance fatigue and its effects on soccer performance indicators. A Division I Women's soccer program was evaluated using GPS to aquire physical performance measures while technical performance measures were aquired from a match analysis platform for all matches ($n = 23$) and halves. To evaluate reductions in team performance between halves, paired sample t-tests were used. Little indication of physical performance fatigue between halves was observed. Total distance and HIR distance were similar between halves. Greater player utilization was observed from the first- to second-half. Technical performance decrement was observed as the team allowed opponents more shots (mean diff: -1.87, $p < 0.001$), experienced a reduced possession percentage (mean diff: 4.20, $p < 0.04$), and reduced passing accuracy (mean diff: 2.95, $p < 0.05$). Together, these results demonstrate that physical performance fatigue was relatively limited from the first- to second-half despite curtailed technical performance which may reflect the increased use of substitutions within a match, reducing technical skill across the program while maintaining physical fitness.

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PREFACE

The NCAA is represented by approximately 45,000 players across three divisions of men’s and women’s soccer. While professional soccer has started to embrace the use of sports scientists to manage training loads and enhance performance, it is unclear who is carrying out sports science and how at the NCAA level. This dissertation serves to: examine who is managing the responsibilities of a sports scientist within the NCAA and what practices are being implemented carry out this role; and expand sports science understanding about NCAA soccer considering its differences from professional soccer. The first study within this dissertation uses survey data collected from soccer coaches, strength and conditioning coaches, sports scientists, and practitioners. The majority of practitioners who identify responsibility for managing and monitoring training loads are sports coaches, followed by strength and conditioning coaches. Relatively few respondents identified as a sports scientist. This suggests further development of these practictioners for the responsibilities of the sports scientist may be valuable to the sport. The second and third studies use training load data captured from wearable technologies commonly employed in the NCAA. Longitudinal analysis of training load data detailed the volumes observed throughout NCAA microcycles while also highlighting differences in training load volume based on player roles. Throughout a season, training load volumes were significantly higher in starters than substitutes and bench players. Although, training load volumes were similar amongst roles on training days whereas starters experienced significantly greater volumes on match days compared to the other two roles. These patters were observed for both men’s and women’s soccer programs. The third study also employed the use of game performance outcome data. Evaluation of training load data and game performance outcome data in NCAA women’s soccer matches across a team suggested that patterns of physical performance fatigue are inconsistent with that observed in professional soccer. Altogether, these findings highlight the unique context NCAA soccer provides and the need for more sports science investigation at this level.

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LIST OF ABBREVIATIONS

FIFA – Fédération Internationale de Football Association

GPS – Global Positioning System

RPE – Rating of Perceived Exertion

VT – Ventilatory Threshold

EPL – English Premier League

UEFA – Union of European Football Associations

MD – Match Day

HR – Heart Rate

FBS – Football Bowl Subdivision

FCS – Football Championship Subdivision

USSF – United States Soccer Federation

IDA – Initial Data Analysis

G - Goals

GA – Goals Allowed

xG – Expected Goals

xGA – Expecteed Goals Allowed

BP% – Ball Possession Percentage

AP% – Accurate Pass Percentage

OD% – Offensive Duels Won Percentage

DD% – Defensive Duels Won Percentage

CHAPTER 1: INTRODUCTION

INTRODUCTION

The investigation of sports performance has grown tremendously during the past five years[1]. The formal investigation of sports performance is often referred to as sports science, or the application of scientific principles and techniques to investigate and improve sports performance[2–4]. Research exploring the dynamics between factors and outcomes of sports performance can provide practical applications leading to success in a competitive sporting environment. The sports scientist represents a unique role, charged with determining which factors contribute to performance while also describing, planning, and monitoring the demands of sport in order to enhance performance[5,6]. Sport science is a multi-disciplinary field, and the role of a sports scientist requires multifaceted expertise, representing areas such as sports medicine, nutrition, analytics, coaching, scouting, and strength and conditioning[7,8]. While many of these roles have long-existed in sport, the sports scientist is a relatively new, emerging role in the United States[7].

The National Collegiate Athletics Association (NCAA) Division 1 level represents just one of the elite sport organizations in the U.S. that is starting to incorporate sports science. The NCAA Division I is composed of 170,000 student-athletes competing in one or more of the twenty-four sports[9]. This level of competition often represents an intermediary level between elite youth sport and professional sport. Success at this level not only provides these athletes opportunities to advance to the professional levels, but also improves financial contributions to athletic departments[10] as well as athlete compensation through Name, Image, and Likeness (NIL) deals[11]. Consequently, there is a strong rationale to succeed at this level beyond intrinsic motivation, prompting NCAA athletic departments and teams to invest in sport performance research. Despite this rationale, it is unclear who athletic departments are tasking with the responsiblity for these research initiatives, what aspects of performance are being investigated, and how other coaches and practitioners perceive this role in terms of responsibility for managing performance and training. To maximize the application and utilization of sports science at the NCAA Division I level, institutions should clarify who is responsible for carrying out sports science and the scope of the role.

Sports performance research requires the evaluation of performance or the effectiveness and efficiency[12] of individuals during sport. While winning is the desired end-product and mark of a successful performance, performance indicators are often used to identify components of competition that contribute to successful performance[13,14]. In essence, successful performances are the effective and efficient execution of multiple aspects of sport such as passing accuracy, shots on goal, or saves. The execution of these actions in isolation during sport will not directly result in the win or loss of a competition; however, they tend to support successful results[14]. Identifying salient performance indicators relevant to a sport provide sports scientists with practical ways to measure and intervene to enhance performance[13].

Although sports science is defined as a multi-disciplinary field, significant attention is paid to the management of training load and its effects on performance[15,16]. Training load can include both internal and external loads. Internal training load references individual physiological and psychological responses to physical work. Examples of this are rating of perceived exertion, heart rate, lactate concentrations, biochemical, hormonal, and immunological assessments, questionnaires or diaries, and sleep[17]. External training load references the physical work performed throughout training and competition[18]. Examples of this include total distance covered, number of accelerations and decelerations, and the number of sprints performed. To measure external training load, sports scientists often employ time-motion analysis technologies such as global positioning systems and accelerometry, which provide volume and intensity measures[5,19–21]. Depending on the time of year or season, training volumes and intensities may be modified to manage the balance among fatigue, fitness, and stress. Fatigue represents the ability to maintain the required or expected force or power output demanded by the sport[17]. Fitness reflects the long-lasting, physical preparedness for the sport that is attained when athletes are exposed to specific forms of stress, such as training sessions or competitions and provided time to recover or return to homeostasis[22,23]. Throughout the course of a season, stressors must be provided alongside periods of recovery to ensure athletes are developing fitness or adapting to the demands of the stressor. Too much stress with inadequate time for recovery, however, will lead to overtraining and subsequently increased risk of injury, illness, and nonfunctional overreaching (fatigue lasting weeks to months)[17,22]. In other words, sports scientists utilize training loads to gauge and manage the risk of overtraining while ensuring training loads improve fitness and prepare athletes for competition performance.

Soccer is one of the sports that has adopted the practice of monitoring training load to manage fitness and fatigue. With some leagues earning the attention of 12 million fans worldwide per match[24], the incentives to schedule more matches throughout a season are considerable. These same professional leagues cap rosters to 25-30 players[25,26]. The players on these professional team rosters tend to fall into starter and reserve subgroups where starters represent players who start matches and reserves represent players who might be substituted into the match[27–29]. As a result, some starting players are expected to play nearly 70 competitive matches a year[30]. This means these players are often expected to play two matches per week. Meanwhile, several studies suggest that the recovery time following a match is 72-hours[31,32]. As teams schedule multiple matches per week, they may hinder player performance by reducing recovery time windows between matches. Subsequently, club practitioners and soccer researchers often use training loads to support high performance and manage fatigue amongst starting and reserve players on their teams throughout a season[18,33–39].

Differences between NCAA and Professional Soccer

While the investigation of training loads and fatigue throughout soccer microcycles and matches is well-documented at the professional level[18,33–39], there are limitations related to the application of these studies within NCAA men's and women's soccer. The NCAA provides a training and competition environment unique to that of professional levels. While professional soccer tends to span 8-10 months, the NCAA season spans 4.5 months. This shortened season comes with a congested match schedule where it is typical for teams to play 2-3 matches per week, totaling 18 games during the regular season. Upon the completion of a match, coaches and players are often expected to begin preparation for their next opponent the following day. Preseason presents another nuance to NCAA soccer. Professional soccer preseasons range between 6 weeks and 10 weeks[40,41] while NCAA preseasons span 2-3 weeks[42]. This means coaches and practitioners have significantly less time to physically prepare athletes for the first match.

During matches, the differences between NCAA and professional soccer become more apparent. While the Fédération Internationale De Football Association (FIFA) recently increased the number of substitutes to five per match, the NCAA allows much more substitution flexibility. Players can exit the match during the first half and re-enter the match during the second. During the second half, players may exit and re-enter the match once[43]. As a result, substitution patterns may have a tremendous effect on the fatigue, or the inability to maintain the expected force or power output, experienced by players and a team throughout a match. Furthermore, the substitution rules introduce different ways to characterize players on a roster. While professional soccer provides starter and reserve roles, NCAA soccer presents the roles of starters, substitutes, and bench players, based on their involvement in matches.

Another match nuance to NCAA soccer is clock management. During professional soccer, the clock continues to run despite stoppages in play. At the end of a match, additional time, called stoppage time, is added to the 45 min half to account for stoppages in play. In NCAA soccer, the match is strictly determined by the 45 min clock. In the event that a goal is scored, a card is shown, an injury occurs, or a player is substituted into the match after the 85th minute, the referee is instructed to stop the clock[43]. It is unclear whether the different clock management rules influence match performance.

Although there are differences between NCAA and professional soccer, similarities like match duration and field dimensions allow sports scientists to employ similar research methods and study designs used in professional soccer to investigate the physical demands of the sport. Matches, regardless of level, are characterized by running, tackling, jumping, accelerating. decelerating, and changing direction while performing technical skills such as passing, striking, and heading. Success during a match is predicated on performing these actions efficiently and effectively at high intensity[44,45]. These movements can be measured and evaluated within NCAA soccer similar to professional soccer[46,47]. It is unclear, however, how the contextual differences of NCAA soccer influence the demands of the match. Additionally, the measurement and evaluation of the physical demands of competition may be further analyzed for their effects on performance indicators.

Differences between Men's and Women's Soccer

FIFA's current aim for women's soccer is to increase participation to 60 million by 2026[48]. While the construct of the game is the same between men's and women's soccer (e.g. 90 minute duration, substitution allowances, pitch size), there are continued calls for more research concerning the evaluation of elite female competition using contemporary physical activity tracking methods[49]. Where topics detailing differences between nationality, competition level, age-level, and playing position are well covered in men's soccer, the coverage of these topics within women's soccer is limited[50]. There are physiological and anatomical characteristics exclusive to females including menstruation, the use of oral contraceptives, and the anatomy of the knee which impact training, performance, and injury risk[49]. Contemporary studies of female players provide new definitions for physical performance parameters like high speed running and sprinting[51] rationalizing the evaluation of competition and training within elite female players using appropriately defined physical performance markers.

Therefore, the purposes of this dissertation are to 1) evaluate the perceptions of the application of sports science and the sports scientist role in NCAA soccer by NCAA Division I coaches, 2) identify the distribution of training load throughout the in-season NCAA men's and women's soccer microcycle with respect to player role, and 3) measure fatigue throughout NCAA women's soccer matches and evaluate the relationship fatigue may have with soccer performance indicators. To support the purposes of this dissertation, the following specific aims and hypotheses are addressed in three individual studies.

SPECIFIC OBJECTIVES AND HYPOTHESES

Objective 1: To evaluate the state of sports scientist roles within NCAA soccer programs and the perceptions coaches and sports scientists hold about the role and application of sports science to NCAA Division I soccer.

- Hypothesis 1a: Coaches will identify greater responsibility for the prescription of training loads for their players throughout the season while identifying sports scientists as less responsible.
- Hypothesis 1b: Coaches will report that sports scientists have greater responsibility for training load monitoring, analysis, and interpretation.
- Hypothesis 1c: Few NCAA soccer programs will have a sports scientist dedicated to their performance. Those that do not will report strength and conditioning coaches carrying out the training load monitoring and reporting aspects of sports science.
- Hypothesis 1d: Coaches will identify themselves to be more responsible for managing and evaluating performance than their sports scientists.

Objective 2: To identify the distribution of training load throughout the in-season NCAA soccer microcycle with respect to player roles.

- Hypothesis 2a: Training loads will be greater for players who hold a starter role than players who hold a bench role
- Hypothesis 2b: Training loads will be similar for all three roles (starter, bench, and substitutes) of players on training days

Objective 3: To measure fatigue throughout NCAA soccer matches and evaluate the relationship between fatigue and soccer performance indicators.

- Hypothesis 3a: Teams will experience decrements to physical performance between the first and second half of a match.
- Hypothesis 3b: Teams will experience decrements to technical performance between the first and second half of a match.

The results of these studies will contribute valuable knowledge to the enhancement of NCAA soccer player performance utilizing sports science. By assessing the perceptions of the sports scientist role within NCAA soccer, sports scientists can better communicate their purpose, counter misinformation held by other practitioners, and better advocate for the resources needed to perform this role. Furthermore, these studies should improve how players are trained and managed throughout seasons and matches in efforts to maximize performance. This dissertation is separated into six chapters. Chapter 2 addresses the current research, providing a review of the literature pertaining to sports science, training load monitoring, and performance within soccer. Chapter 3 addresses Objective 1 (Perceptions of sports science), Chapter 4 addresses Objective 2 (Training load distribution throughout the microcycle), and Chapter 5 addresses Objective 3 (Effects of fatigue on match performance). To conclude, Chapter 6 provides a summary of the findings within this dissertation and provides avenues for further study.

CHAPTER 2: LITERATURE REVIEW

LITERATURE REVIEW

Introduction

The National Collegiate Athletic Association (NCAA) oversees twenty-four sports across three divisions. Its top-tier, Division I, hosts more than 170,000 student-athletes competing on a national-scale[9]. Like many elite sports, the implications of success at this level can have social and financial benefits for individuals and organizations. Recognizing these benefits, the emphasis on success at this elite level places pressure on university athletic departments and their coaches to ensure student-athletes have the tools and resources for optimal performance. In an effort to create the environment for optimal performance, athletic departments are building out performance staffs and departments equipped with strength and conditioning or athletic performance coaches, sports dietitians, mental skills coaches,sports psychologists, and performance analysts.

More recently, the role of sports scientist has been added to these performance staffs with varying degrees of expertise and responsibilities. While some athletic departments have added full-time sports science positions, others have attempted to incorporate the responsibilities of a sports scientist into a strength and conditioning or athletic performance coach's role[52,53]. This pattern may be reflective of the perceived role of the sports scientist as a sport technology manager, viewing the sports scientist as responsible for the management of technologies such as global positioning system (GPS) microsensors or force plates. Although these technologies are valuable for the applications of sports science and provide important information about athlete and team performance, their association with sports science as the primary or sole responsibility of the sports scientist is concerning. This association seems to reflect the lack of understanding about the sports scientist's role within the collegiate athletic environment.

Perhaps one of the reasons the sports scientist role has been associated with sport technologies is their applications to measure fitness, preparedness, and fatigue. These components, fitness, preparedness, and fatigue, are influenced by training and the time following training allowing for recovery[23]. Technologies such as heart rate monitors, GPS monitors, accelerometers, etc. can be used to assess the total volume, intensity, and density of training while also providing measures indicative of fitness and fatigue[19,54]. While alternative means to capture measures of intensity and volume of training load exist (i.e. Session RPE), these new, emerging technologies seem to have captured the attention of sport practitioners have become associated with the sports scientist role.

Therefore, the purpose of this literature review is twofold. First, to define sport science and the functions of sports scientists in elite sport environments and second, to detail how sports scientists are using training load as a tool to monitor fatigue and fitness throughout the season to drive performance.

The Sports Scientist Role

The role of the sports scientist has been examined since the 1970's when it was presented as a performance identification role[55,56]. Clemente and colleagues (1979) used the term "sports scientist" to discuss a researcher responsible for identifying performance characteristics of elite runners. The researcher was responsible for collecting various physical performance measures which were provided in a statistical model to estimate long distance running ability[55]. Since that time, the function of the sports scientist has expanded from the role of a physical performance measurer while remaining focused on achieving optimal performance.

Contemporary researchers exploring sports science define sports science as a discipline studying the application of scientific principles and techniques in order to improve sports performance[2–4,52]. This means incorporating the practices of presenting and testing a hypothesis to provide a framework to understand something of interest[2]. This definition infers an applied component of sports science that requires a combination of research, development, application, and innovation while incorporating an array of research questions originating from a plethora of research fields[2]. In their analysis of sports science research, Williams and Kendall (2007) group sports science areas of study into biomechanics, physiology, nutrition, psychology, medicine, physiotherapy, pedagogy, and other, highlighting the variety of research domains applicable to sport[57]. Perhaps because of the wide scoping role of the sports scientist, Sands recommends sports scientists seek broad training rather than a narrow lens of study[2]. The role and the research questions asked within the role should provide sport stakeholders (i.e., coaches and athletes) the information necessary to perform at a high level within the sport. This may require the ability to contextualize and discuss performance related issues from multiple research disciplines. Sport stakeholders may benefit most from sports scientists with an advanced yet generalized understanding of performance.

Despite the consensus that sports science is a research-intensive role, sports scientists, caught in the intersection of sports and research, must balance a practitioner role working within elite sport environments with the functions of a scientific researcher. As a practitioner, sports scientists are faced with a high-pace environment where innovation, efficiency, and effectiveness are expected to be applied to performance[58]. Sports scientists are often expected to work directly with teams, providing training, coaching, or direct consultation with the athletes throughout day-to-day operations. Recent terminology such as research-practitioner, have been used to describe this combined role[8,59]. Still, many questions remain pertaining to the sports scientist's role within elite sport environments, the scope of their practice, and the purpose of this role. As a result, the purpose of this section is to define sport science and the functions of sports scientists in elite sport environments. Further, this review will examine best practices for the sport science role with elite sport environments.

What is Performance?

If sports science is intended to investigate and modify factors of performance using scientific methodology, it is critical to first address the question, ‘what is performance?’. Seeking the answer to this question within the field of management, Ghalam and colleagues (2016) conclude that “performance” is a multidimensional term with no single definition. The broadest definition, they present, entails a practice of effectiveness and efficiency[12]. Within sports, performance has been analyzed since the 1960’s when U.S. football and basketball teams began using coded notes to analyze outcomes during competition[14,60,61]. While the elements of performance, effectiveness and efficiency, are desired within sport, the definition of performance seems to hinge on whether an individual or team wins within the context of competition. Perhaps this reflects being more effective and efficient than opponents during competition, but the question is, in what way? Specifying how athletes and teams can be more effective and efficient by identifying how competition outcomes occur can provide ways to monitor and modify those aspects of performance[62].

How do teams or athletes win? As sport coaches and analysts began addressing this question, they began dissecting the contributing factors to winning. Review the box score at the end of a competition, and one might find a few measures observed throughout competition. Considering these measures more, it will be apparent that the box score provides insufficient detail for how these measures identify which areas should be improved in future practices or training sessions. Coaches and analyst break down competition to identify characteristics, metrics, or factors that are indicative of game outcome. These factors are often referred to as key performance indicators[14]. Key performance indicators are a selection of action variables or combinations of multiple action variables that contribute to overall performance[13]. They are parameters that are associated with successful outcomes. Parameters like the earned run average of a baseball pitcher, the effective field goal percentage of a basketball player, or the possession percentage within soccer represent key performance indicators. They provide information about the opponent's run-scoring ability, the offense's ability to score, or the team's ability to retain the ball, respectively. These parameters are indicative of the outcome of a competition but do not independently predict performances. They hold a degree of explanatory power for identifying which athletes may perform well in competition[63].

Performance indicator selection is contingent upon the sport, contextual factors associated with the sport, the dynamics of competition, and the individual or group of interest. The structure of the studied sport should be considered when determining performance indicators. Sports can be grouped in closed skill or formal game sports. Closed skills include acrobatic, athletic, and cyclic sports[13]. Successful execution of closed skills can contribute to performance success. For instance, an acrobatic competition like beam within gymnastics requires the ability to execute technical maneuvers with limited mistakes to achieve the highest score. Cycling sports, meanwhile, require cyclists to complete a race distance faster than their competitors. These sports differ significantly from formal games, which are subcategorized as net and wall games, invasion games, and striking and fielding games[13]. Success within these sports is still reflected by the ability to outperform opponents but involve the execution of biomechanical, technical, and tactical skills[13]. Again, the difference amongst sports highlights the knowledge of the sport required of a sports scientist to perform their duties effectively and investigate the sport responsibly.

Sports scientists must develop a deep understanding of their studied sport to investigate performance indicators relevant to coaches and analysts. Analysts and coaches may use performance indicators to evaluate performance at the individual-level, team-level, or sub-team level (i.e., position group, starting player rotation, etc.)[13]. Similarly, sports scientists should consider performance at each of these levels. This may require an understanding of positional differences and tactical strategies within the context of a team. These considerations may improve the selection of performance indicators. Once selected, these performance indicators should be considered with caution. A single performance indicator, such as possession percentage within soccer, has limited applications when used in isolation from other variables[14]. Possession percentage alone cannot be used as the sole predictor of performance and may be dependent on a multitude of other factors. For instance, possession percentage may reflect the competition site, field conditions, weather, opponent, player skill, tactical formation as well as many other contextual factors. Without understanding the sport, many of these contextual factors may go unconsidered as sport scientists intend to investigate performance.

The nuances that are presented at the individual- and team-level of sports present different goals and expectations for the scientific practices performed by sports scientists. Where other scientific research is concerned with generalizing results and findings to the greater population, sports science tends to be more concerned with providing meaningful and purposeful results or feedback that are specific to individual athletes and team behaviors[64]. This means the goals of research are more focused on internal validity than external validity[2]. The ability to apply findings to a broader population is less important than identifying patterns and trends within the individual or team because the purpose of sports science research is to identify and provide performance advantages specific to single players or teams. To further provide performance advantages, evaluations are performed comparatively, when applicable, relating the performance of the team to another team or individual players to a position-group within a team[13]. For example, if maximum velocity is identified to be a key performance indicator of performance for the outside back position for a specific soccer team, comparing the maximum velocities of all outside backs on the roster may provide coaches with valuable information about which players would perform well in the outside back position. Alternatively, if the most technically skilled player is identified to have one of the lower maximum velocities on the roster, the sports scientist may recommend that player train in such a way to improve their running speed. These types of feedback function to provide coaches practical ways to improve their team.

Who Benefits from Sports Science?

Recognizing the role of the sports scientist to examine and enhance performance, it is necessary to identify whom sports science research is intended to benefit. An effective sports science service includes a strong research base and the adoption of research findings by practitioners in the sporting environment[57]. These practitioners can represent coaches, operations, scouts, physicians, athletic trainers, massage therapists, rehabilitation therapists, strength and conditioning coaches, dietitians, performance analysts, as well as others in the sport environment[8]. To be effective, sports scientists must engage ”working-fast and working-slow” practices to keep pace with the fast-moving environment while ensuring the data and research are scrutinized before implementing changes determined from results[65]. When quickly available, understandable, and implementable, sports science research may be utilized by practitioners for the benefit of their athletes[52]. Care should be taken, however, to ensure that the implementation of sports science research undergoes thorough interrogation. Sports scientists should be cautious of working so fast that they fail to perform proper methods or jump to a conclusion that is only partly supported by results.

Provided the amount of time spent with and directing athletes, it should be unsurprising that coaches represent a primary beneficiary of sports scientists. Coaches function to provide the physical, technical, tactical, psychological, and theoretical training to prepare athletes for successful performances[3,66]. Access to knowledge and novel training methods could greatly improve coaching practices to develop successful athletes. In many ways, coaches seek information to improve their athletes' performance. When available, sports scientists can translate and communicate scientific information adapting and interpreting scientific research and materials for the application to coaching practices[66]. When unavailable, coaches, depending on their personal scientific backgrounds, may fall victim to gimmicks, fads, or misleading information[52]. Exposing athletes to training methods or interventions presented by these gimmicks, fads, or misleading information may put athletes at risk of harm or injury or simply be ineffective for improving performance. Improving the quality of information available to coaches while filtering out misleading information could greatly improve training methods and athlete performance.

Sport coaches represent one of the primary audiences or beneficiaries of the sport scientist[56,66]. While coaches carry out the responsibilities of delivering direction, instruction, and training for sports teams and individual athletes[3], they operate similarly to clinical physicians[66]. Coaches are often limited by time, must act on intuition before all the facts can be made available, and rely on the traditions, consensus of colleagues, and advice of mentors to guide their decision-making process[66]. This presents a large degree of uncertainty in decision-making and presents coaches' decision-making process as a 'shot-gun' approach[66]. To reduce this uncertainty, and to improve coaches' decision-making as it applies to athlete performance, sport scientists can serve as science communicators for their coaching staffs, supplying them with relevant, scientific information about training and performance problems. Sports scientists should work alongside sport coaches who are responsible for directing, instructing, and training sports teams and individual athletes[3]. In doing so, they may equip coaches with a stronger knowledge base, relying less on anecdotal experience or tradition, to direct, instruct, and train their athletes and teams.

While this function of sports scientists seems straightforward, coaches identify that the questions or problems sports scientists attempt to resolve are irrelevant to the areas where coaches need help[2,3,66]. This may reflect a failure, on behalf of the sport scientist, to address the needs of their coaches in two ways. First, sports scientists seem to fail to engage their audience by relying on language and communication modalities used to engage the scientific community. Second, sports scientists appear to fail in identifying what questions coaches are asking. Addressing these failures may improve sports science buy-in from coaches.

Sports scientists attempting to improve the sport environment should integrate into the environment to better understand the problems faced by coaches and learn the language utilized within the sport. Sports coaches report preferring their sports scientist be knowledgeable about their sport of study[3]. This often requires firsthand experience within the sport either through experience as an athlete or by becoming heavily integrated into the sport environment. Bartlett and Drust (2021) describe this process of integrating into the sport environment as becoming an embedded research-practitioner who develops technical knowledge, practical skills, and interpersonal craft development necessary to contextualize, translate, and disseminate performance-related information to other stakeholders in the sport environment[8]. Within this capacity, the sports scientist can develop a skillset for presenting findings, using the language of the sport environment, that are easily integrated and accessible for sport coaches and athletes[3]. Developing a firsthand understanding of the sport, sport scientists can better engage coaches and athletes by utilizing a shared language.

Sports scientitsts may also find firsthand experience particularly useful to addressing research questions important to coaches, effectively improving buy-in from the coaching staff. Therefore, practitioners should identify which research questions are relevant to the needs of the coach and provide applicable findings[3]. By improving coaching staff buy-in, sports scientists may observe greater willingness to deviate from established norms and traditions, improving sports scientists' ability to suggest and implement changes to current practices. Collaborating with sport coaches to identify research questions could also reduce a common critique coaches present, that many sports scientists become caught up in research questions that are too difficult to apply to their coaching practices[3]. While sports scientists are trained to perform research and present their findings in a way that engages the scientific community, these formal presentation and publication modalities can be intimidating and complex by audiences who are not part of the scientific community[2]. Rarely are sports scientists trained to translate their research to coaches or athletes[52]. Sport scientists who can structure large-scale, timely research projects into smaller, quickly produced projects with implementable findings may be more valuable to sport coaches than those focused on producing formal research for the scientific community.

How is Sports Science Perceived?

In addition to the number of reviews and discussions conceptualizing the role and function of sports science, a handful of studies have examined how the incorporation of sports science in the sport environment has been perceived by coaches, athletes, and other practitioners[67–73]. The majority of these studies were performed in elite sport contexts while only one evaluated perceptions of sports science in the U.S. This presents a couple of issues. First, the bulk of studies performed internationally reflects what Stone (2004) described as a lack of formal sports science educational programs in the U.S[52]. Limited development of sports science in the U.S. would contribute to limited ability or need to assess coaches' perceptions of sports science. Further, cultural differences present different results or expectations from coaches in regard to the role of the sports scientist and knowledge acquisition[70]. Brink and colleagues (2018) determined that Dutch soccer coaches prefer to acquire knowledge through modalities such as journals, books, television, online social networks, and Youtube[72]. Meanwhile, Williams and Kendall (2007) report Australian coaches prefer learning through workshops, networking, and sport-specific magazines[56]. In the U.S., sports scientists should identify the preferred modality of learning from their coaching staff in order to best present new performance knowledge. Delivering sports science knowledge catered to the learning preferences of the coach may improve how coaches perceive sports science.

A second issue arising from the current literature detailing coach perceptions of sports science is the focus on coaches within professional or elite sport contexts. Rauff and colleagues (2022) described the current understanding of sport science utilization in collegiate settings as unknown prior to conducting their qualitative analysis of collegiate coaches to address this question. In the U.S., coaches from the NCAA or college athletics organizations are presented with unique situations where sports science may be carried out by an academic department, provided by one individual to multiple sports, or unavailable completely due to budgetary limitations. Despite the issues presented from the current research detailing coach perspectives of sports science, there are a few consistent themes that arise from these types of studies which may be applied to sports science in the NCAA.

There are five major themes that coaches reports as barriers to using and applying sports science. These themes include the applicability of sports science to coaching, conservatism, language barriers, time, and financial resources[70]. Understanding these perceived barriers may help sports scientists develop strategies to overcome these hindrances.

Although sports science is intended to support performance, coaches have reported the research performed by sports scientists to be unapplicable to their coaching practices[70]. Coaches consistently agree that addressing ways to improve mental and physical skills and techniques are highly important to the development of high performing athletes and teams[67,71,72]. Krkeljas and colleagues, however, found coaches to report the greatest contributions made by sports scientists are related to peaking for competition, reducing injury, and developing recovery strategies[67]. Within Weston and colleagues' study of coach perceptions of training load monitoring, coaches and practitioners both report the primary purpose of training load monitoring is to maximize performance. Further, practitioners specifically report an emphasis on enhancing fitness[16]. Similarly, English Premier League (EPL) sports science practitioners also ranked improving performance and management of training load distribution as most important[15]. While it seems clear that sports science has found a niche in optimizing performance by managing training loads, this focus on physical fitness and recovery has limitations. Coaches are tasked with providing technical and tactical skill instruction in addition to providing mental and physical skill development. If sports science is intended to better equip coaches, yet the emphasis has been on physical fitness and recovery, the lack of applicability reported by coaches may reflect a need for sports scientists to reevaluate the focus of their research questions or contextualize the applications of their findings to skill development. Practitioners should address concerns about applicability by aligning their research questions with that of the coaching staff and organization, establishing a list of expectations and usable outcomes from the research questions[70].

When faced with a performance related question, coaches must determine how to address this question. While sports scientists function to help address these questions, conservatism represents another barrier to coaches fully utilizing their sports scientist. Conservatism reflects the adherence to tradition or the unwillingness to embrace new training ideas[70]. It represents the most reported perceived barrier to applying sports science in Dutch football clubs[72]. Conservatism may stem from two characteristics of how coaches learn. First, coaches report that other coaches represent a primary, preferred knowledge source[67,71]. As coaches develop throughout their careers, personal relationships or mentorships are developed with other coaches. Coaches are more likely to seek answers from these fellow coaches before involving other practitioners, which results from a preference for personal contact and shared experiences[70,71]. This may explain differences between more and less experienced Turkish coaches' perceptions of how well sports science research meets their knowledge needs[71]. Sports scientists may find the most success in providing coaches with new information and seeing sports science applications implemented when they develop similar relationships and promote social interaction with a coach.

Second, coaches often have extensive playing and coaching experiences which serve as a knowledge-source. Coaches report self-reflection of these experiences as a source of answers to performance related questions[72]. In other words, coaches develop training methods derived from their experiences as a player instead of scientific knowledge. For this reason, Stoszkowski and Collins (2016) recommend targeting and challenging pre-existing values and beliefs coaches hold around training[74]. Sports scientists may find success in observing how coaches develop practices and train their players then asking questions highlighting the desired outcomes and benefits of these methods.

A third theme presented by coaches concerns the scientists' lack of sport knowledge[72]. Both coaches and sports scientists from English soccer reported that the experience of the practical environment is needed to plan a training week[16]. Krkeljas and colleagues report that coaches prefer that sports scientists have coaching and playing experience[67]. While coaches typically progress into a coaching career from playing the sport, sports scientists may not have that firsthand experience of a player. Playing experiences provide for skill development and understanding of tactics, strategy, and mental training. Sports scientists with firsthand playing experience may better translate information to the coach by contextualizing the findings specifically to the sport, tactical strategy of the team, and level of competition[70]. When sports scientists lack this experience, additional time and effort should be invested in understanding the sport, potentially attending tactical coaching courses or team meetings[70]. Acquiring and continuing to develop a systematic understanding of the sport, a scientist, working alongside a team, may reduce concerns that sports scientists are unknowledgeable about their sport.

The final two themes presented by coaches as barriers to sports science implementation are also reported by sports science practitioners. Lack of money or financial resources represents a significant barrier to incorporating sports science[15,59,67,71,72]. Sports science can be costly. To perform sports science, a scientist is often desired to perform the formalized research process. Presented the domains encompassed by sports science, more than one researcher is often desired. While interviewed in Krkeljas, Tate, Vermeulen, and Terblanches' (2017) study, one coach expressed concerns funding a biokineticist, physiotherapist, sport psychologists, fitness coach, and dietician in aim of providing sports science[67]. While professional organizations are beginning to incorporate a practitioner to fulfill the applied responsibilities of these roles, the formalized research process can be costly and often requires somebody with an additional research skillset to carry out these processes. Bartlett and Drust (2021) recommend addressing this issue by hiring a research-practitioner who can carry out the applied practitioner responsibilities while contributing the applied experience to academic research and course studies[8]. In doing so, organizations fill the sports science role with capable practitioners and outsource formal research to academic research institutions.

Still, by reducing the number of people an organization needs to hire or contract research, the organization is still faced with the challenge of providing the resources to incorporate applied research. Weston (2018) surveyed coaches and sports science practitioners on the training load monitoring, identifying that English soccer clubs often use GPS, heart rate, blood lactate, rating of perceived exertion just to monitor training load. As organizations seek to address other research questions, the list of equipment and measurement tools can become endless, placing additional strain on the financial feasibility of carrying out sports science. Between funding the personnel and the resources necessary to perform sports science, it is unsurprising coaches identify this as a significant barrier to implementing sports science.

Another constraint tied to the financial barrier of sports science is the available time to carry out sports science. Fullagar (2019) suggests this may be a greater issue with lower-level coaches who do not have the financial support or personnel to implement sports science strategies[70]. Without these resources, coaches cannot fund sports science research nor the research-practitioners capable of carrying out this research. For organizations who can employ practitioners, additional time limitations are presented. This limitations, reported by practitoners bar the formation of collaborative sports science research patnerships dedicated to research amongst a network of practitioners and academics[59]. While these collaborative networks are not necessary to the practice of sports science altogether, they allow practioners to make decisions that have direct impact of practice while academic researchers carry out quality control, critical analysis, and validation of methods, enhancing the sports science program long-term[58,59]. Equipping organizations with more practitioners may improve this situation, but the reported time barrier may also reflect the 'working fast' dynamic of sport described by Coutts (2016)[58]. Malone and colleagues (2018) reported that practitioners need to cater to the 'working fast' nature of sport providing fast, automatics, intuitive, non-invasices applications to training[58,59]. To maintain relevancy and provide competitive advantages, sports scientists need to provide practical applications regularly. Some decisions, such as day-to-day training modifications, are dependent on measurements performed the day of training. Much academic research is described as 'working slow' because of its slow, deliberate, focused, high-effort nature[58]. To balance the focus on daily initiatives, Meur and Torres-Ronda (2019) recommend sport scientists manage the pace of working within sport by establishing a framework of short-, mid-, and long-term goals[7]. Implementing a prioritization plan can allow sports scientists to balance 'working fast' and 'working slow' applications within a 'working fast' environment, limiting the impact time has on the success of sports science.

While there are several barriers reported by coaches to incorporating sports science within their organization or program, coaches appear in agreement that sports science is beneficial to their athletes' performance. Despite athletes being another primary consumer of sports science, few studies have considered their perceptions of sports science. Krkeljas and colleagues (2017), during interviews with athletes, determined the perceived experience working with a sports scientist to be positive; identifying that the sports scientist contributed to various aspects of sports performance improvement[67]. Further, athletes report interest in seeing the data collected by sports scientists and report that such information would contribute to effort levels during training[75]. This presents a unique role of the sports scientist. In addition to providing knowledge to the organization that could be used to modify how athletes are trained, sports scientists seem to have an interactive effect with athletes and how they train. Further investigation into these effects could provide additional value to the role of sports science.

The bulk of research investigating coach perceptions of sports science occur within professional sports settings[3,15,16,67,74]. The perception of sports science applications and barriers held by coaches in the collegiate sports settings may be similar to professional coaches but the research on this subgroup of coaches is limited[73]. Coaches, from a variety of sports at a single Division I institution, identified areas of interest included fatigue and recovery, training methods, and athlete monitoring[73]. This study suggests coaches at the NCAA level are interested in using sports science to improve the performance of their athletes. Martindale and Nash (2013), however, report that some coaches perceive sports science to be less relevant at sub-elite levels[3]. Provided the NCAA represents an intermediary level between junior and professional-level competition, perspectives may vary amongst institutions and sports. Future studies should evaluate coaches perceptions and beliefs about sports science across multiple institutions, sports, and divisions[73].

Sports Science in Multidisciplinary Teams

Although coaches and athletes represent the primary beneficiaries of sports science, the application of scientific principles and techniques to determine factors of performance extend to multiple other disciplines. Further, the practice of sports science, using scientific methods to identify and improve on performance, may be carried out by these other disciplines or stakeholders within the sport environment. Amongst these disciplines include strength and conditioning, exercise physiology, rehabilitation, sports nutrition, sports psychology, etc.[8]. When multiple disciplines are represented within an organization, the subsequent team is described as the multidisciplinary, sports performance team. Multidisciplinary departments or teams represent a group of practitioners working within the sport environment to “help” the athlete. Derived from the healthcare field, multidisciplinary teams in sports tend to precipitate from athletic departments and sport organizations providing athletes access to various professional services[76]. As these various professionals work alongside their athletes, their mutual aim to support the athlete’s performance and well-being integrates individual practitioners into a collaborative team[8]. As each of these disciplines performs its own performance science, their findings may influence decisions made by players, coaches, and administrators pertinent to athletes’ performance, selection, signing, and availability for training and competition[8,63]. Bartlett and Drust (2021) describe sports scientists’ role within multidisciplinary teams as knowledge translators, taking knowledge from one area and helping provide it to another[8]. To accomplish this, sports scientists tend to work within sport organizations in one of two ways.

The first way is described as the traditional reductionist method of applied sports science where sports scientists and other stakeholders operate individually on specialized, isolated projects[77]. For example, a coach may be interested in why their soccer team is allowing goals in the final stages of competition. The exercise physiologist may suggest the observed performance reflects physical fatigue resulting from low muscle glycogen levels[45]. Meanwhile, the sport psychologist may suggest the team is experiencing mental fatigue in late stages of the game after practicing vigilance and emotional regulation throughout the match[78]. Each practitioner presents a hypothesis, carries out their methods and analysis, and determines why the team is allowing goals late in matches and presents how athletes could be trained or prepared differently to reduce late goals. Through this method, the coach is provided a solution based on each practitioner's observations independent from the other practitioners. The criticism of the traditional reductionist method, however, is that it leads to siloed and fragmented interventions providing for poor athlete development and performance[77]. While each practitioner investigates the hypothesized cause of this performance, recommends interventions, and deems that their approach is correct, each practitioner fails to consult with the others. The athletes, meanwhile, are barraged with "correct" methods to improve performance, ultimately *selecting the intervention they determine best*. While this approach to addressing performance represents a multidisciplinary approach where practitioners from multiple disciplines are involved in performance, the variety of opinions and additional issues created by having these opinions has led to sports performance teams transitioning to more collaborative methods.

The alternative to the traditional, reductionist method reflects operating within a transdisciplinary team[77]. A transdisciplinary team collaborates to solve performance problems by integrating principles from different disciplines. The integration of these principles allows sports science teams to use shared context dependent vocabulary, encourage innovation, and collaboration[77]. Within this organizational structure, we might observe a similar scenario where a coach approaches the team with a performance-related issue like late-match fatigue. The team collaborates to identify the factors which are potentially contributing to the fatigue late in the match and determines a single strategy which is communicated to the coaching staff. Through this process, a single message is shared with the coaching staff, which may be conveyed similarly each of the stakeholders, whereas within a traditional, reductionist method, messaging provided by various stakeholders may be perceived as fragmented, irrational, or antagonistic.

This review is intended to address the growing role of sports science in collegiate athletics. To do so, it is necessary to define this role and the responsibilities of carrying out sports scientists. While sports scientists roles range from the 'working fast' nature of practitioners to the 'working slow' nature of researchers[58], all are caught in the intersection of sports and research, delivering high performance innovations to their organizations. As practitioners, sports scientists are faced with a high-pace environment where innovation, efficiency, and effectiveness are expected to be applied to performance[58]. Meanwhile, as researchers, they are expected to observe evidence-based practices and innovations while upholding ethical practices[58]. Research-practitioners face the challenege of balancing each of these roles. Coaches identify that applicability of sports science to coaching, conservatism, language barriers, time, and financial resources present barriers to the success of sports science[70]. Meanwhile, the involvement of other practitioners within sport presents challenges and the need for multidisciplinary team development. Future research-practitioners should be cognizant of these challenges and proactive to determine solutions which will improve sports performance throughout an organization.

Applying Sports Science to Monitor Soccer

The initial part of this review investigated the role of the sports scientist within a sport organization. Identifying that this role functions to provide coaches, athletes, and other practitioners information and knowledge pertaining to performance, the subsequent review examines applications of sports science to soccer. Specifically, this portion of the review will detail methods of time-motion analysis as it is used for training load monitoring and discuss what measures provided by time-motion analysis are used in soccer and why these measures are typically selected. Finally, this review aims to examine how these markers contribute to on-field, match performance. By doing so, this part of the review provides a rationale for how sports scientists working with soccer can effectively measure and improve understanding of sport performance within their sport organization.

Quantifying and characterizing the demands of soccer can provide extensive information to coaches and practitioners about how to train players for optimal performance. Numerous studies describe soccer as a dynamic, physically demanding team sport which requires athletes to run, tackle, jump, accelerate and decelerate, and change direction while performing technical skills such as passing, striking, and heading[44,45]. The efficient and effective execution of these actions at a high-intensity throughout the course of a match may provide an advantage over opposing teams. As a result, sports science practitioners have aimed to measure these demands and identify how players sustain high-performance throughout a match and season using an array of methods. These methods include quantifying training load, which encompasses external and internal training load, psycho-physiological load, mechanical load, stress, and strain[79]. One method, time-motion analysis, is commonly used to quantify the volume and intensity of training loads in soccer[80,81].

Time-Motion Analysis

Valued by coaches and managers for the provision of physical exertion measures of external training load, time-motion analysis is commonly used throughout soccer. Time-motion analysis refers to the measurement of times spent in different modes of motion[82]. Using time-motion analysis, practitioners may determine what movements are occurring at each moment of training and competition within each player. Aughey (2011) distinguishes that time-motion analysis is measuring the outputs of each player[20], which may provide valuable, quantified information about physical exertion and stress, positional workloads, and training intensities performed by each player[19]. Early time-motion analysis involved video-based recordings which were used to evaluate the movements of a single player[83]. Since, the use of tracking systems such as optical tracking, global positioning systems, local positioning systems, and accelerometers have been employed to perform time-motion analysis[84]. This has greatly improved the feasibility of time-motion analysis for soccer clubs and organizations. Where time-motion analysis used to be highly labor intensive, time consuming, and therefore, often confined to university research, it is now computerized and subsequently more practical, allowing clubs and organizations to perform real-time analysis of on-field player performance[19,81]. For global position system and accelerometer technology in particular, the benefits include lower costs and greater portability[20]. This allows teams to use time-motion analysis on the road or away from their home pitch.

Another benefit of newer time-motion technologies is the turn-around time of analysis. The collection and analysis of data from these devices occurs at a much faster rate than traditional time-motion analysis technologies. Each player can be equipped with a monitoring device which records data live. Players' data can then be assessed post-match or training, whereas previous time-motion data had to be recorded for each player individually by reviewing video records of the player throughout the training or match. This greatly limited the turnaround time of these data. As many soccer clubs and organizations desire reports to be available within 24-36 hours post-match[81], the latter method is not feasible for this application. These advancements, consequently, have greatly improved the use of time-motion analysis throughout soccer.

Despite the benefits of time-motion technologies such as global position systems and accelerometers, there are some limitations. Technologies like these often do not meet quality control requirements of reliability, objectivity, and validity[81]. For tools intended to measure physical outputs of players, practitioners must know that these tools measure activity accurately and consistently to appropriately manage training and assess competition demands. Carling, Bloomfield, Nelsen, and Reilly (2008) argue that the lack of a single validation test protocol is responsible for the absence of these requirements[81]. Since arguing this, some validity and reliability of these monitoring technologies have been reported, supporting the use of global positioning system and accelerometry units[85,86]. Nevertheless, practitioners should evaluate quality control requirements before employing in their clubs and organizations.

Perhaps as a product of poor-quality control amongst time-motion analysis technologies, comparing physical activity between different devices is often avoided. Metrics often vary amongst devices[5]. Many practitioners identify distance covered at various speed thresholds, accelerations, and decelerations to be measures of time-motion analysis and activity profiling highly pertinent to team sports[15,64] yet different thresholds are reported by different device manufacturers. This presents challenges comparing one manufacturer's time-motion analysis technology to another, which can lead to additional challenges comparing data across multiple teams and leagues. When players move from one club or organization to another, their physical performance data may change, reflecting different technologies as opposed to changes in performance.

Provided the differences amongst technologies, practitioners should also consider both the capabilities of the technology as well as the demands of the sport before selecting a time-motion analysis technology. In their review of global positioning systems validation and reliability studies, Scott, Scott, and Kelly (2016) report that 1Hz and 5Hz units are less accurate for measuring high-intensity running and velocity measures compared to 10Hz and 15Hz units[87]. If sports science practitioners are only concerned about total distance, they could use 1Hz or 5Hz units. In a sport like soccer, 10Hz units are necessary to accurately measure high-intensity activity. Using these technologies, practitioners can begin to quantify these outputs at the long-term, macro block, weekly, daily, drill and period levels improving the process of describing, prescribing, and planning physical work.

Although there are limitations to time-motion analysis technologies, these tools serve well to measure the demands of competition, assess training across teams and individuals, and prepare athletes throughout the season. In other words, time-motion analysis serves sports scientists to perform three major applications: describing, planning, and monitoring[5]. These three applications are subtly different and each crucial to the preparation of high performing teams.

As sports scientists describe the demands to competition, they develop an activity profile. Activity profiling reflects the goal of characterizing the physical demands of competition, transitioning from measuring player outputs which are more reflective of individual effort[20]. The demands of competition are often greater than the individual physical outputs of players. If players were to entirely dictate the demands of competition, it would be expected that they would not experience fatigue to the degree that it inhibits skill performance throughout competition[20]. Instead, fatigue is commonly observed throughout a match thus suggesting the demands of competition are greater than the physical capabilities of each player. Therefore, activity profiling is valuable as it may be used to plan how players should train and prepare for matches while providing a standard for comparison to determine athlete’s preparedness for competition.

While activity profiling and description provides an understanding of what the physical demands of competition and matches should be, sports scientists should be prepared to track changes in team and individual athlete performances across matches. Monitoring summarizes this objective and allows practitioners to guide decisions about individual performances and injury risk[5,88]. From competition to competition, individual performances are anticipated to fluctuate; sometimes in response to the contextual factors of competition and sometimes in response to individual changes in fatigue and fitness status[35,89]. The role of monitoring is to evaluate the interaction between planned and observed physical output or training loads and analyze how individuals and teams are responding to these training loads[5]. By monitoring, sports science practitioners can suggest changes to training plans, based on objective information about how players are responding to training.

The final application of time-motion analysis, planning, aims to provide organizations with a program for physical output or training loads[5]. Where coaches may plan based on subjective impressions of team and individual performance, time-motion analysis allows for the prescription of objective training load goals[5]. These goals are often established for different timeframes such as day-to-day training plans to weekly or seasonal training load goals[90]. The incorporation of training load description and monitoring provides practitioners with the ability to determine what teams and athletes should be preparing for, planning training based on these targeted loads, and adjusting the plan according to athlete responses.

By describing, monitoring, and planning activity, time-motion analysis can be beneficial to sports science practitioners. Practitioners develop an understanding about how athletes and teams should be prepared which limits the possibility of under- or over-training entire teams , while also observing individual responses and training loads which improve prescription and planning for each individual athlete. To fully capitalize on the value of this tool, it is critical to determine what physical performance measures are indicative of performance.

Applying Time-Motion Analysis to Soccer

From the casual viewer's perspective, soccer may appear to be a sport primarily consisting of a constant state of running. Following this logic, teams that run more are more likely to win throughout a match. This perception would be supported by estimates of energy expenditure within soccer. Early measures of energy expenditure in soccer determined that players' average oxygen consumption throughout a match is 70-80% of their VO_2max[91]. This observation would seem to support the notion that soccer is performed at a constant state of running provided the high-intensity of the match; yet, several studies report that half of matches are spent standing or walking for both males and females[92,93]. In order to cover reported distances of 8-11 km, players must perform repeated bouts of running at high-intensity; intermixing these periods with low-intensity recovery bouts[45]. This provides a layer of complexity to measuring the demands of the sport. Practitioners must account for changes in intensity, the frequency, and duration of the different movement actions during competition. To quantify these actions, time-motion analysis techniques have been applied to determine the demands of competition and training.

Activity profiling studies have provided detail about what players do throughout a match and which external training load parameters are associated with on-field performance. Early activity profiling methods involved a single observer who characterized match activities[80,92]. Often these activities would be qualified as standing (0-6 km•h^{-1}), walking (6-8 km•h^{-1}), jogging (8-12 km•h^{-1}), low-speed running (12-15 km•h^{-1}), moderate-speed running (15-18 km•h^{-1}), high-speed running (18-30 km•h^{-1}), and sprinting (>30 km•h^{-1}) by the observer[34]. The observer would record the frequency and duration each activity as it was performed and then calculate the total distance covered throughout a match based on the duration and velocity of each event[34]. From these analyses, early studies performed in soccer were able to identify the running demands of the sport and lay the foundation for future research evaluating the role of running in soccer.

The velocities defining activities in the early activity profiling studies stem from Bangsbo's (1991) pilot study of elite male soccer players[92]. As more precise instruments of time-motion analysis have been introduced, velocity thresholds have been adjusted. Many industry and academic researchers now define standing (0.0-0.7 km•h^{-1}), walking (0.7-7.2 km•h^{-1}), jogging (7.2-14.4 km•h^{-1}), running (14.4-19.8 km•h^{-1}), high-speed running (19.8-25.2 km•h^{-1}), and sprinting (>25.2 km•h^{-1}) in the men's game[35,94]. Other researchers investigating elite men's soccer appear to have adopted these definitions[38,94,95].

Velocity thresholds have also been adopted and applied to elite female soccer although there is less consensus for accepted thresholds. Several studies report high intensity running in female matches to be ~30% lower than males of similar quality[93,96]. Bradley, et al.(2014) demonstrated large gender differences exist for covered high intensity running and high-speed running distances (determined by > 12km•h^{-1} and > 18 km•h^{-1}, respectively). Alongside other studies[97–99], this evidence supports the hypothesis that female players possess a lower aerobic and anaerobic physical capacity than their male counterparts. Park, Scott, and Lovell (2019) recommend thresholds of high-speed running (12.5-19.0 km•h^{-1}), very high-speed running (19.0-22.5 km•h^{-1}), and sprinting (≥22.5 km•h^{-1}) based on their analysis of international female soccer players[51]. In addition to differences in velocity thresholds based on sex, velocity threshold differences should be anticipated for different chronological age-groups[84]. These differences are derived from varying physiologically capacities observed for age and sex during absolute sprint and aerobic fitness tests[99]. Practitioners should consider these factors as they implement absolute velocity thresholds to analyze workloads within their athletes. Failure to do so can result with inaccurate profiling of activities throughout training and matches and consequently impact the effectiveness of training load prescriptions.

Despite improvements to time-motion analysis to quantify training loads, the recommended velocity thresholds are well-contested. As soccer and other team sports practitioners adopt Bangsbo's (1991) speed thresholds, researchers and practitioners challenge how these velocity thresholds were determined suggesting alternative velocity thresholds should be applied[84,95]. Much of this disagreement is rooted in the application of absolute and relative velocity thresholds. Absolute velocity thresholds, like the ones previously listed, allow comparison across a team. Practitioners can compare players with each other to determine who performed the most high-speed running (19.8-25.2 $km \bullet h^{-1}$) within a match. This can be advantageous for identifying which players work the most throughout a match which is important as matches are competed at an absolute level[84]. In other words, many moments within matches are not determined by which players run at the highest percent of their maximal speed effort but instead are determined by which players can run the outright fastest. As a result, players who can run faster and do so repeatedly have a distinct advantage over slower players.

Absolute thresholds, however, do not reflect individual effort. Determining the effort athletes put forth individually may be more important for monitoring fatigue and physical work. Relative velocity thresholds allow practitioners to identify which players put forth the most effort on a team and account for differences in individual capacity[84]. One method to determine relative velocity thresholds employs sprint tests to establish maximum running velocity[84]. The 40 m sprint test represents a commonly used test to determine velocity thresholds[100]. Once assessed, practitioners may elect to assess the time or distance spent running at, for example, 80% of maximum running during training and matches as a measure of high intensity workload[100–103].

An alternative relative threshold method utilizes ventilatory thresholds (VT_1 and VT_2) to demarcate three individualized speed zones: low, moderate, and high speed running[104,105]. Lovell and Abt (2013) present that individualized speed thresholds determined by physiological markers better reflect the intensity of exercise performed by an athlete than absolute thresholds. The use of ventilatory thresholds indicates the energy demands of a training session or match[104]. Using the ventilatory thresholds, velocity zones can reflect the intensities of running when lactate begins to accumulate in the blood, VT_1, and when blood lactate accumulates at a rate greater than it can be cleared, VT_2[106,107]. These zones then reflect activities that can be maintained: a. for a long time with relatively no fatigue, low speed; b. for longer durations but fatigue will eventually set in, moderate speed; or c. for short durations before fatigue rapidly occurs, high speed. To acquire the running velocity reflective of these thresholds, however, a ramped treadmill test to exhaustion is used while player's expired air measured[104]. Although this method provides highly individualized velocity thresholds reflective of individual physical capacities, it requires specialized techniques and equipment that may not be available to all sports science practitioners. Furthermore, while these speed zones reflect the intensity of work performed by an athlete, it is difficult to infer exactly how fast a low, moderate, or high speed run will be using these zones adding complexity to the comparison amongst athletes. The value in providing individualized, time-motion analysis information, however, is that athletes can be better compared to their themselves based on their own capabilities.

Although advancements could be made to the development of velocity thresholds in soccer, their application in time-motion analysis continues to provide valuable insights to the physical demands of the sport. Practitioners should consider their population and goals of analysis when selecting velocity thresholds. As detailed by the studies investigating velocity thresholds, each selection has strengths and weaknesses which may reflect the capabilities and resources of a sport organization.

Activity Profiling of Soccer Matches

Activity profiling research has contributed understanding about the physical demands of the soccer. During early studies, researchers used total distance to measure mechanical work output as an indirect measure of energy expenditure[108]. Bangsbo (1994) reported that male players (body mass: 75 kg; VO_2max: 60 ml•kg^{-1}•min^{-1}) average an oxygen consumption of 70% VO_2max throughout a match[91]. Within female players, the estimated oxygen consumption during a match is estimated to be 77-80% of VO_2max[49,93]. Further, elite male and female players typically cover approximately 11 and 10 km, respectively, throughout a match[49,108]. For context, male players average a running speed of 7.2 km•h^{-1} while female players average 6.7 km•h^{-1} to cover this distance over ninety-minutes. Within their review of time motion analysis studies in elite soccer, Carling and colleagues (2008) determined male elite soccer players cover 9-12 km per match while female elite players cover 8.7-12 km per match[81]. Furthermore, positional differences in both men's and women's soccer should be expected. Amongst male players, midfielders tend to cover the highest distance while central defenders tend cover the least throughout a match[35,94,109–113]. Similar tendencies have been observed in female players, although far fewer studies demonstrating these positional differences are available[96,114–116]. From this information, a sense of the total running volume is provided, supporting rationale for total distance goals during training to prepare for match volumes.

Studies detailing total distances in soccer provide one measure of the mechanical work demanded by the sport, but do not describe the high-intensity activity within matches. As previously discussed, soccer is an intermittent, interval sport with periods of high-intensity activity interspersed with periods of low-intensity activity. Total distance accounts for the total running that occurs throughout a match but cannot be used to distinguish these changes to intensity. To begin physically preparing players for periods of high-intensity activity, practitioners must assess the frequency and volume of high intensity periods throughout a match. Mayhew and Wenger (1985) identified that the ratio of high intensity running to low intensity activity was approximately 1:7 amongst a group of elite male players during matches[80]. Bangsbo (1991) reports that elite male players spend a total of 7 min of exercise at high intensity during a match. On average, players perform 16-19 sprints spanning a mean duration of 2.0s[35,92]. Practitioners should also consider the recovery periods or periods of low intensity activity between high intensity periods. Within the EPL, for example, the mean recovery time, or the time elapsed between running bouts greater than 19.8 $km{\bullet}h^{-1}$, was 72s[38]. From these observations, it is apparent that these periods are highly frequent, very intense, but short-lasting in matches.

Additional time-motion analysis studies in soccer argue the importance of high-intensity running to success within matches[37,95,117]. High intensity running refers to sum of all running covered in the running, high-speed running, and sprinting zones. In their original investigations of energy demands in soccer, Bangsbo et al. (1991) reported high intensity running to include all distances covered at a speed > 15.0 $km{\bullet}h^{-1}$[92]. This velocity was selected as it was the approximate speed for maximal oxygen uptake within elite male soccer players[91,92]. For females, the velocity of running at VO_2max is reported to be 12.0 $km{\bullet}h^{-1}$. Mohr, Krustrup, and Bangsbo

(2003) emphasize that high-intensity exercise is a valid measure of physical performance in soccer based on their observation that top-class male players perform a greater frequency and percentage of the match high-speed running and sprinting compared to moderate players[34]. Studies investigating the locomotor demands of elite men's soccer report that high intensity running accounts for 10% of the distance covered during matches[37].

Top-class female players are also reported to cover significantly more high intensity running distance than those at a lower competition level[96]. These studies contribute that as quality of play increases, so does high-intensity running distance. It would seem that high-intensity running becomes increasingly important to succeed in higher levels of competition, but Carling (2013) cautions that more high-speed running may not always correlate to success. Other factors reflecting the tactical and technical elements of play are also determinates of match outcome. Further, high-speed running or other physical performance measures may be influenced by tactical and contextual factors of the match[118]. Practitioners should consider preparing players for the demands of matches, recognizing that demands are higher in more elite leagues, while avoiding contributing improvements to physical performance directly to success.

High intensity running appears to be affected by league success as well[35,37,119]. In a study of players from a men's Union of European Football Associations (UEFA) Champions League team, significantly more high intensity running was covered against a team's best opponents compared to its worst opponents[35]. In the EPL, teams were characterized as top, middle and bottom league teams based on their league position at the end of the season. Top teams performed less high intensity running and sprinting than middle and bottom teams. Bottom teams performed more sprinting than middle teams[37]. From these results, more successful teams appear to have to work less to manage games. Practitioners may anticipate less successful teams to run more at high intensity throughout matches.

Positional differences in higher intensity running distances are observed, too[38,47,94,96]. Bradley and colleagues (2009) observed wide midfielders to perform the greatest very high intensity and high intensity running distances compared to central defenders, fullbacks, central midfielders, and attackers. Wide midfielders and fullbacks covered the greatest sprint distances amongst the playing position groups[38]. Similarly, men's players competing in the Spanish Premier League demonstrated central defenders perform less high intensity running than other position groups. Forwards, outside midfielders, and fullbacks covered similar sprint distances, which were significantly greater than those covered by central midfielders and central defenders[94]. Within the NCAA, forwards and midfielders were observed to cover a greater percentage of total distance at high-speed compared to defenders[120]. Both studies highlight that playing formation may affect the high intensity distances covered by different positions[38,94].

Amongst elite female soccer players, similar patterns of high intensity running are observed; however, insufficient sample sizes have led some researchers to use three positional groups, attackers, midfielders, and defenders, compared to the five commonly reported in men's research[39]. Within women's soccer, defenders are reported to cover significantly less high-intensity running than attackers and midfielders[96]. Contrary to this observation, Hewitt, Norton, and Lyons (2014) determined defenders and midfielders to cover greater high intensity running distances than attackers at the Australian national team level[116]. At the NCAA collegiate level, female attackers were observed to cover the greatest high intensity running distances amongst these three position groups, however, this observation was determined from a single team[47].

Practitioners comparing the positional differences should be wary of contextual differences presented by leagues and levels of play.

Fatigue in Soccer

Throughout time-motion analysis literature pertaining to elite soccer, researchers reinforce that physical fatigue is occurring during matches[34,38,44,96,112,121]. Fatigue is defined as the failure to maintain a required or expected power output[45,109] and therefore, represents a considerable factor of match performance. During a match, players may experience fatigue acutely, reflecting a momentary decline in expected power output following peak intervals of play, or chronically, reflecting reduced power outputs towards the end of a match[37,38,44,45,91,121]. Both temporary and chronic fatigue represent concerns to the performance of teams, as a reduced capability to maintain work-rate can provide opponents a physical advantage. Practitioners should be cognizant of how physical fatigue develops, both temporarily and chronically, monitor actions that contribute to physical fatigue throughout matches and training, and design training to reduce the influence of physical fatigue during matches.

Temporary Fatigue in Matches

Physical fatigue and the ability to maintain work-rate is well discussed in the context of soccer through a physiological lens[34,45,109,122,123]. Where fatigue is well-studied in other physiological studies of individual sports, soccer presents a unique dynamic in which work-rate is selected by the demands of competition in addition to self-selection of exercise intensity[109]. The intensity of most individual sports is determined by athlete self-selection or pacing. These studies highlight that physical fatigue is attributed to the short- and long-term metabolic demands of a match and therefore can partly be explained by the performance of each energy system.

Temporary fatigue, or fatigue that players may recover from during the match, tends to be reflective of anaerobic capacity, or the performance of the phosphocreatine and glycolytic energy systems[38,122]. The intense events observed during a match utilize creatine-phosphate to produce adenosine triphosphate. During a period of low intensity activity, creatine-phosphate is quickly resynthesized for later use[122]. Bangsbo, Iaia, and Krustrup (2007) point out that the creatine-phosphate levels never become critically low during matches where maximal performance would be inhibited[122]. Krustrup and colleagues demonstrate the reduction to creatine-phosphate levels anticipated during a match using the Yo-Yo Intermittent Recovery Test, a test intended to mimic the repeated running demands of sports like soccer. After elite male players completed the Yo-Yo test to exhaustion, muscle creatine-phosphate levels were observed to be insignificantly lower than before the test[124]. This observation suggests that within matches, creatine-phosphate levels are declining but are not affecting players' ability to perform their sport.

If temporary fatigue is not the product of phosphocreatine system performance, it is reasonable to conclude that this short-term fatigue is induced by glycolysis and the accumulation of by-products such as lactate. Several studies assessed the changes in blood lactate during matches, observing average concentrations range from 2 to 10 mM[92,93,125,126]. Players experience increases in blood lactate, suggesting glycolysis is active, yet the production of lactate is still not considered the cause of temporary fatigue. Krustrup and colleagues' (2003) study of the YoYo Intermittent Recovery 1 test for applications to soccer observed blood and muscle lactate at YoYo Intermittent Recovery 1 test exhaustion significantly increased from their concentrations at rest. This is consistent with in-match assessments of blood lactate. Lactate is a by-product of glycolysis when pyruvate cannot be used in oxidative phosphorylation and can be measured as it accumulates in the muscle, where it is produced, and the blood, where it can be transported from the muscle. Muscle and blood lactate measures can be used to estimate the contributions of glycolysis during exercise[91]. Krustrup and colleagues (2003) observed that muscle lactate concentrations at YoYo test exhaustion was significantly greater than resting concentrations. Further, muscle lactate at 90% exhaustion was not different than muscle lactate at exhaustion. Krustrup and colleagues (2003) observed blood lactate to significantly increase throughout the test[124]. These findings indicate that glycolysis is highly active during activities like soccer but does not cause fatigue via the production of lactate. Short periods of high intensity during a match likely use glycolysis extensively leading to the production of lactate. If this high intensity activity were sustained, players would inevitably experience fatigue. Instead, periods of low-intensity recovery allow other tissues in the body to use blood lactate, reducing the inhibitory effects of lactate in the active muscles by allowing lactate to continue spilling into the blood[91]. While muscle lactate and glycolytic activity do not seem to be the direct causes of temporary fatigue, they should be considered alongside other factors such as muscle pH and ATP which lower, and muscle inosine monophosphate, blood ammonia, and plasma potassium which increase during matches[122].

A plethora of studies have considered fatigue throughout matches using time-motion analysis[34,38,91,92,94]. In support of temporary fatigue in matches, these studies typically compare differences within players between pre-determined time intervals (i.e. every 5 min, every 15 min)[34,96,97]. Evidence of temporary fatigue has been provided for both elite male and female players[34,96]. For example, male players at various elite levels perform significantly less high intensity running during a 5 min period preceded by the 5 min period when the greatest high intensity running occurred[34,38,97]. Top-class female players also covered significantly less distance during the next 5 min following the 5 min period of peak high intensity running[96]. These observations support that highly intense periods induce fatigue which players cannot maintain throughout an entire match. To compensate, players recover from these high intensity periods by running less during the subsequent periods.

Chronic Fatigue in Matches

Chronic fatigue, typically observed during the final stages of a match, is reported to reflect depletion of muscle glycogen stores and increases to core body temperature[83,91,109,127]. Saltin (1973) observed glycogen concentrations in the thighs of a group of soccer players to decline from pre-match concentrations of 96 $mmol \bullet kg^{-1}$ to post-match concentrations of 9 $mmol \bullet kg^{-1}$. In a second group, players started with pre-match muscle glycogen levels of 45 $mmol \bullet kg^{-1}$ and completely depleted these stores by the end of the match[83]. Jacobs and colleagues (1982) performed muscle biopsies on elite male soccer players three times (immediately post-match, one day post-match, and two days post-match) to quantify total glycogen content and glycogen repletion during the days following a match. Jacobs and colleagues (1982) observed that immediately post-match muscle glycogen concentrations within the leg were 63% of the concentration observed two days post-match when players should have replenished muscle glycogen levels[127]. These studies demonstrate that muscle glycogen levels decline substantially during a match to the point of depletion. Recognizing the role of glycogen to maintain the endurance and explosive power demands of soccer, it is clear that these activities severely deplete muscle glycogen stores but the performance of theses activities is also impacted by the reduction of muscle glycogen levels late in a match. Practitioners should consider monitoring the volume of endurance and explosive power activities throughout a match and consider when players will experience reduced ability to continue carrying out these activities.

Supporting the physiological mechanisms of chronic fatigue developing throughout a match, several time-motion analysis studies describe the differences in player performance between the first and second half[34,37,96,112]. Mohr and colleagues (2003) reported that top-class players cover less distance in the second half of matches[34]. Barros and colleagues (2007) also reported a significant, 7% decrement to total distance covered between halves by male Brazilian soccer players[112]. Bradley and colleague's (2009) examination of high intensity running during men's EPL games determined that high intensity was most pronounced during the final 15 min of matches when distances were 18-21% lower than other periods within the match[38]. Differences between halves, however, are not necessarily guaranteed. Di Salvo and colleagues (2006) identified no significant differences between halves in male Spanish Premier League players[94]. Di Salvo and colleagues (2006) did, however, observe that moderate- and low-speed running, jogging, and walking distances decreased during the second half, suggesting that players maintain high intensity distance coverage during the second half by increasing the distance covered by walking and jogging while reducing distances covered at medium intensity running[94].

Within women's soccer, differences between halves have been reported for top-class female players. Mohr (2008) reported significantly greater total, high intensity, and sprint distances during the first half of matches[96]. Interestingly, a study of UEFA Champions League women only showed differences between halves for total distance covered and distances covered < 15 km•h^{-1}[39]. Players did not exhibit a reduction to high intensity running whereas UEFA Champions League men did between halves[39]. The similarities amongst these studies, demonstrating less covered distance later in men's and women's matches, supports the notion that players are fatigued during the second half of matches and therefore unable to maintain the volume of running performed during the first half.

Other studies investigating the occurrence of chronic fatigue compare the final periods of matches to the first period of the match[34,38,39,96,116]. Top-class elite men's players demonstrate significant reductions to total distance covered and high intensity running distance covered during the final 15 min of a match compared to the first four 15 min periods of matches[34]. High intensity running in the elite men's soccer is observed to decline in each 15 min period compared to the first but is most pronounced in the final 15 min period of each half[38,97]. Oliva-Lozano, Fortes, and Muyor (2021) extended findings on this trend, observing that the number of sprint actions were less frequent during the second and final 15 min periods of each half[128]. This may reflect the fact that recovery time, or the time between very high-intensity bouts of running, was significantly longer during each of the three final 5 min intervals of matches compared to the first 5 min interval[38]. Players may be increasing the recovery times during these later stages by limiting how often they perform high intensity runs. Among Australian Women's national team players, Hewitt (2014) determined that total distance and high intensity running distance significantly declined during the final two 15 min periods of a match compared to the first[116].

While there is indication that teams experience chronic fatigue throughout a match, it is unclear whether chronic fatigue differs amongst positions. Mohr and colleagues (2003) identified reductions to high intensity running during the second half relative to the first in each playing position of male top-class players[34]. In a study of male EPL players, however, all playing position groups, except attackers, performed less high-intensity running during the second half of a match compared to the first[38]. Another study of EPL players presented greater decrements in high intensity running occur in wide midfielders and attackers while central midfielders and central defenders completed similar high intensity running distances between halves[37]. Interestingly, a study of UEFA Champions League men's and women's players presented no significant differences between halves for any men's position groups. Central midfielders and wide midfielders ran less distance > 12 km•h^{-1} during the second half but no further differences were observed in any position[39]. Mohr and colleagues (2008) observed less high intensity running and sprinting in all positions for high-level and top-class female players but no differences amongst position groups[96]. Similarities between halves were also observed in the men's Spanish Premier League for measures of total, high-speed running, and sprint distances[94]. The discrepancies reported amongst these studies for player position fatigue may be explained by differences in activity profiles across leagues and levels of play. The UEFA Champions League, for instance, represents the best clubs from each league in Europe, raising the level of competition. Studies evaluating the effects of player position on chronic fatigue should consider these contextual factors before projecting anticipate declines in performance.

Provided the descriptive evidence of temporary and chronic fatigue in studies of soccer, practitioners should consider planning and monitoring accordingly. Some decline in work-rate can be anticipated, however, work-rate decline will vary based on age, sex, league success, and position as well as other factors. Practitioners should also consider the effects of fatigue on other measures such as high intensity running, sprinting, accelerations, and decelerations through the context of their team or organization. After doing so, assessing these decrements for each player and monitoring players throughout a match can enhance decision-making for when to substitute players, adjust training to improve physical fitness or reduce fatigue entering the match. Still, individual match context presents a source of additional complexity. Carling (2013) warns that many of the changes between halves or amongst intervals of play are reflective of other contextual factors such as tactics, ball possession, and score line[118]. Interpretation of these changes should include individual physiological, or internal training load, responses to monitor performance decrements throughout a match.

Influence of Substitutions on Fatigue

In elite soccer, the number of players allowed to substitute into a game is limited, meaning that many players are on the field for the entire match. This presents a dynamic within the match between fatigue and physical performance that differs from many other sports. Mohr and colleagues (2003) showed that substitutes entering the game before the 75th minute had higher work-rates during the final 15 min period than players who played the entire match[34]. Unfortunately, in elite soccer, substitutes cannot be provided for every player who started the match prompting coaches and practitioners to make decisions about which players to substitute. Reilly and colleagues (2008) recommend prioritizing players with the greatest decline in work-rate throughout the match. Essentially, this method highlights the players experiencing the greatest fatigue and replacing them with new players.

Other levels of soccer present unique substitution rules that complicate this recommendation. The NCAA for instance, allows players to reenter the game in the second half if they are substituted out during the first. In the second half, players may reenter the game one additional time if they are substituted out of the second half. Furthermore, there are no limitations on the number of substitutions allotted to teams during a match[43]. Teams could, essentially, substitute their entire starting roster off during the first half and then start them again in the second. This nuance highlights the need to explore fatigue more intensively at this level and present better recommendations for substitution patterns to maintain work-rates throughout matches.

Training Load Monitoring throughout the Microcycle

In soccer, training load monitoring is often used to manage the volume and intensity of training and maximize recovery from fatigue and limit the effects of fatigue on performance during matches[17,129]. Training loads during a training session are likely to reflect a variety of factors such as time of season, schedule congestion, relation to match, and player position and role[33,42,129–134]. While coach and organization philosophy ultimately determine the volume and intensity of training, some patterns have been observed throughout the microcycle of period of training sessions going into a match[42,133]. Practitioners often categorize training based on the relation to the next match (i.e., MD-3 is three days before the next match, MD+1 is one day post-match)[18]. The bulk of these studies, performed in men's soccer, suggest that training loads are reduced as teams approach match day. For instance, Spanish La Liga men's players trained at the greatest intensity and volume on MD-3 and MD-4 or MD+1[133]. EPL men's players covered greater distances on MD-3 compared to MD-2 and MD-1 during 1- and 2-match per week schedules[129]. Another English Premier League study observed that training volumes were lowest for total distance, high-speed distance, and very high-speed distance on MD-1[130]. Amongst five NCAA Division I men's teams, MD-2, MD-3, MD-4, and MD-5+ elicited greater total distance and high-speed running distances covered compared to MD-1. MD-5+ had significantly greater total distance and high-speed running than any of the other training days[42]. Generally, these studies suggest that coaches tend to reduce the training load volume in preparation for matches. This is not surprising as a fully recovered player should be able to perform better during a match.

Several studies have considered whether players are trained differently throughout the week according to position[18,33,130]. Positional differences are observed in activity profile studies suggesting that players experience different physical performance demands based on their position. Studies investigating the training loads of soccer positions identify differences in weekly accumulate loads amongst positions but attribute this to the inclusion of match data[130]. While Kelly and colleagues (2019) observed attackers covering greater total distance on MD-1 than wide defenders and central defenders[130], Malone and colleagues (2015) reported limited positional differences[18]. These inconsistencies suggest that training loads are going to differ amongst clubs and programs and, while previous studies provide a reference for positional training loads, coaches and practitioners should consider their positional training loads within the context of their own team.

One other factor that should be considered when planning training loads is player role. Depending on the level of play (i.e., professional, collegiate, youth), different roles will be presented. In professional soccer, roles have been presented as starter, fringe, and non-starter[33] based on the number of starters a player accumulates throughout a season. In college soccer, this type of role categorization is less applicable because players can substitute in and out of matches more often. Instead, it may be worthwhile to distinguish players as starters, substitutes, and bench players as observed in college basketball, which has similar substitution allowances[135]. Ultimately, the importance in distinguishing player role lies in the training loads accumulated throughout the season. Anderson and colleagues (2016) observed that starters accumulated greater duration, total distance, and distances at running, high-speed running, and sprinting compared to fringe and non-starters in the men's EPL[33]. While matches account for much of these discrepancies, the trend presents concerns for the training status of fringe and non-starter players should they be promoted mid-season. To account for this, coaches and practitioners may want to increase the volume of training for these roles on days after matches. It seems that this may be occurring in men's collegiate soccer already. Curtis and colleagues (2020) report that reserves cover slight, but insignificantly more total distance and high-speed running distance than their starter counterparts[42]. Future studies should investigate season accumulated loads, accounting for match volumes, specific to player role in the NCAA.

Relationship between physical performance and match performance

Ultimately, the relationship between physical performance and team success is the link sports scientists need to identify to rationalize monitoring physical performance. Without this relationship, there is no reason to control for physical performance as it would have little to no contribution to a team winning or losing. Interestingly, Rampinini and colleagues (2007) state that physical performances are not associated with success[35], which begs the question why so much research is committed to monitoring physical performance. Instead of directly relating to wins and losses, physical performance is more likely to impact the technical proficiency of players during matches[35]. Technical proficiency is key to improving statistical measures in a match like ball possession, number of shots, shots on target, number of passes, and pass completion rates[136–139]. Further, technical proficiency performed at high intensity can be highly influential to the end result of a match[123]. These measures have been associated with team success which would suggest that improvement of technical proficiency could indirectly lead to greater team success.

Some examples of associations between physical performance and technical proficiency are reported. In the case of physical fatigue, Reilly (2008) argues that muscle fatigue experienced during matches may affect technical performance. Several studies detail the effects of physical fatigue on technical skill in soccer[140–142]. Apriantono et al. (2006) induced fatigue, albeit to the point of exhaustion, on the legs of soccer players and assessed their performance of an instep kick. Players were observed to kick with less force and less coordination when fatigued[141]. In amateur male and female soccer players, kicking produced ball speeds significantly slower during a fatigued state[142]. These controlled trials ultimately demonstrate that fatigue can greatly affect technical performance particularly for a movement like kicking which is used to pass and take shots. Practically, these effects should be explored within the context of matches particularly for measures like passing accuracy and ball possession percentages as these are contingent on technical skill execution.

To explore the relationship between physical performance and technical performance, it is necessary to identify the performance indicators of technical performance. Performance indicators represent a selection or combination of performance variables which reflect a competition element of performance[13]. When applied appropriately, performance indicators suggest what future performance should be anticipated[143]. Castellano, Casamichiana, and Lago (2012) provide a description of methods for determining which variables were indicative of success during the 2002, 2006, and 2010 World Cups. Comparing the variables of winning, losing, and drawing teams, the variables total shots, shots on target, total shots received, and shots on target received best discriminated between winning, losing, and drawing teams[136]. In theory, teams that can enhance their ability to shoot on target often while limiting their opponent's shots and shots on target should have a better chance of winning in future World Cups. Still, Collet (2012) suggests caution when determining performance indicators. While investigating the value of possession in competition, Collet (2012) determined that, in general, European teams were more likely to win when they had greater possession[137]. Further examination of possession tendencies revealed, however, that this relationship between possession and competition success was driven by the best teams within European leagues. When these teams were removed from analysis, possession was a poor predictor of match success for non-elite teams[137]. In fact, teams were more likely to lose when they possessed the ball more[137]. Provided these findings, one might conclude that the key to competition success is greater possession for elite teams and less possession for non-elite teams. Collet (2012) point out, however, there is a difference between quality possession and mere possession where quality possession reflects passing leading to quality shot opportunities and mere possession simply reflects retention of the ball[137]. This example suggests that practitioners should be wary of using performance indicators as outright predictors of success. Different contextual factors should be considered when selecting and applying performance indicators.

Despite the presented time-motion analysis research and the growth of performance indicator research in soccer, little has been done to evaluate physical performance effects on performance indicators using time-motion analysis data[36]. Such research could allow practitioners to identify the contributions of fatigue to a technical performance indicator, like passing accuracy, or consider the advantage work-rate provides in maintaining possession throughout a match. These questions should be considered and contribute valuable understanding about the importance of physical performance to overall match performance.

Practitioners should recognize that soccer is a combination of physical, technical, and tactical aspects which contribute to how a match is played[113]. This review emphasized that the role of sports scientists is to explore and evaluate components of performance using scientific methods. Incorporating this practice into the context of a sport organization can enhance the practices of sport and performance coaches as well as other practitioners to contribute to team success. As this role continues to develop, sports scientist practitioners should continue to consider and acknowledge the needs of their organizational members, recognizing that these needs will vary amongst members and shift throughout time.

CHAPTER 3: EVALUATING COACH AND PRACTITIONER PERCEPTIONS OF SPORTS SCIENCE AND ITS APPLICATIONS TO NCAA SOCCER

ABSTRACT

Sports science, the application of scientific principles and techniques to investigate and improve sports performance, is commonly employed in soccer by formal sports scientists to assess how players respond to training. NCAA men's and women's soccer has started to adopt sports science technologies, yet it is unclear who is responsible for carrying out the sports science responsibilities. As a result, this study aims to evaluate the perceptions of sports science applications and the sports scientist role in NCAA soccer. An online survey consisting of 50 questions about practitioner demographics, program capabilities and practices of training load monitoring, training and practice planning, and training load monitoring feedback was circulated to coaches, strength and conditioning coaches, sports scientists, athletic trainers, and other practitioners via email. Respondents (n = 187) most commonly identified as a sport coach (n = 128), followed by strength and conditioning coaches (n = 45) and sports scientists (n = 13). The most commonly used traning load monitoring tools were questionnaires and session rating of perceived exertion (sRPE). Training planning was typically the responsibility of the head coach. Verbal, informal communication was the most common communication channel (62.6%) used to deliver training load information throughout a program. Based on the findings of this study, the sport coach represents the practitioner most commonly responsible for monitoring and managing training loads and sports science applications within NCAA soccer programs (n = 128, 68%). Resources and trainings about training load monitoring and management aimed towards this audience may serve beneficial.

INTRODUCTION

Sports science is the study and application of scientific principles and techniques to investigate and improve sports performance[2–4,144]. Sports science can involve the study of biomechanics, physiology, nutrition, psychology, medicine, physiotherapy, pedagogy, or other research domains within sport contexts[57]. Each of these domains contribute to performance, or the efficiency and effectiveness, of athletes during competition[12]. To carry out research in these areas, sports scientists are often hired to serve as interdisciplinary practitioners in sport organizations[8]. These individuals are responsible for conducting the sports science investigations and translating their findings into practical applications which may be implemented by coaches, athletes, or other practitioners[8,144].

The National Collegiate Athletic Association (NCAA) represents one of the organizations which has recently started to witness employment of sports scientists in its participating programs. Other organizations such as the EPL, Australian Football League, and the Australian Institute of Sport have utilized sports scientists since the early 1990's[57], establishing the responsibilities of role and expectations[7]. In the NCAA, the responsibilities and expectations of the sports scientist role are unclear and likely to vary amongst different programs or univerisities[7]. Where sports science is carried out by a practitioner with a formal title of sports scientist in Australia or the United Kingdom, individuals such as strength and conditioning coaches or data analysts are claiming the role in the United States[145,146]. Furthermore, the establishment, expectations, and applications of sports science are highly dependent upon the sport to which they are applied[70]. Consequently, there is a need to investigate this emerging role within the context of specific NCAA sports.

Soccer represents one the NCAA sports starting to utilize sports science. Several studies have investigated the use and application of sports science in soccer[3,15,16,72]. Within soccer, sports scientists are particularly desirable because of their ability to assess players' physiological states or responses to training[15]. To carry out this responsibility, sports scientists often use tracking systems such as global positioning systems (GPS), accelerometers, and optical tracking to determine the demands of training and competition[5]. This practice reflects the capture of external load, or the work, completed by players[17]. Other measurement tools exist, however, to assess players' responses to training. Measures like perception of effort and heart rate (HR) reflect internal load, or the physiological and psychological stress experienced by the player, and are also used within soccer[15,17]. Both external and internal load are highly valuable for determining training loads and the effects of these loads on performance[17]. Sports scientists can communicate this information to coaches, helping to support direction of the coach and the balance between managing training loads while ensuring players have the skills necessary for competition[15]. In carrying out their role, sports scientists could be highly beneficial to NCAA soccer programs as they provide coaches an assessment of players responses to training.

As sports scientists determine which factors affect performance and develop practical applications, coaches may reap the benefits of more efficient and effective training practices, as well as less fatigued and higher performing athletes. This presents coaches as one of the primary beneficiaries of sports science information. Despite this benefit, the transfer of sports science knowledge to coaches is reported to be poor[6]. Several studies have explored how coaches perceive or utilize sports science and showed significant variation amongst coaches on the relevancy and usefulness of sports science[3,15,16,73]. Akenhead and Nassis (2016) identified that low coach buy-in is a contributing factor to how impactful sports science can be within an organization or team[15]. To combat this, Akenhead and Nassis (2016) recommend communicating effectively with coaches to determine which strategies coaches want to employ to improve their players[15]. Weston (2018) examined how necessary coaches and sports scientists perceived experience within the practical environment (sport) are to plan a training week. Both coaches and sports scientists agreed that practical experience was necessary for planning[16], supporting Akenhead and Nassis's (2016) recommendation that sports scientists understand how coaches intend to improve their players during training.

While sports scientists should ensure they have practical knowledge of the sport they support, they may also want to ensure coaches have adequate scientific knowledge to utilize sports science for the training practices. Weston (2018) asked coaches and sports scientists how necessary scientific knowledge was to plan a training week, determining that each group agreed that scientific knowledge was necessary. Akenhead and Nassis (2016) suggested that coaches with a poorer understanding of scientific knowledge related to their sport may find difficulty utilizing their sports scientist or implementing their recommendations[3]. Amongst coaches at a NCAA Division I university, a major concern was the effective presentation of sports science data from sports scientists to coaches[73]. Athletic departments and teams incorporating sports scientists into their performance models should consider how coaches may be educated about sports science and how coaches can use sports science information to improve coaching and training practices[73]. Currently, the majority of research committed to studying how coaches use sports science to improve their practices is limited to professional sports[15,16], with only one study investigating this in the NCAA[73].

Considering the growth of sports science and training load monitoring tools in NCAA soccer, it is necessary to determine how coaches view sports science. It is currently unclear what coaches and sports scientists expect from the sports science role at this level of competition. While studies in professional sports expose concerns about poor coach buy-in, communication gaps between coaches and sports scientists, and poor scientific knowledge amongst coaches, these concerns have not been formally identified in the collegiate sports environment, a context where sports scientists are still emerging. Therefore, this study's purpose was to evaluate the perceptions of sports science applications and the sports scientist role in NCAA soccer. Provided the work performed by Akenhead and Nassis (2016) and Weston (2018), we expected sports science practitioners to include individuals hired under the titles of sport coach, strength and conditioning coach, and athletic trainer, in addition to sports scientist. Because sports science is relatively new to NCAA soccer programs, we anticipated that few NCAA soccer programs would have a sports scientist dedicated to their performance; and those that did not would be represented by another performance practitioner carrying out the sports science responsibilities.

METHODS

This study was approved by the University's Institutional Review Board. The study was intended to explore who was responsible for carrying out sports science in the NCAA, determine what resources these individuals had, and determine how sports science was being applied. This exploration was performed using an online survey, with closed- and open-ended responses, which were circulated amongst NCAA Division I, II, and III soccer programs to target individuals who carried out the sports science responsible for the program. Sports scientists, were also identified from the National Strength and Conditioning Association sports science and soccer special interest groups, and the Collegiate Strength and Conditioning Coaches Association. The online survey was distributed for a 6-week span from July, 2023 to September, 2023.

Participants

Coaches, strength and conditioning coaches, sports scientists, athletic trainers, and other practitioners were invited to participate in this study if they currently work with an NCAA institution, men's or women's soccer program and were identified as the primarily responsible practitioner for the monitoring and management of training load throughout the season. This definition of practitioner built upon the Akenhead and Nassis (2016) definition recognizing that many NCAA programs may have sport coaches carrying out the roles of the 'practitioner' observed in elite level soccer[15]. To further understand who might represent the sports scientist practitioner in this setting, participants were asked to identify which role: sport coach, sports scientist, strength and conditioning coach, athletic trainer, or other most closely described the position they for which they were hired.

All potential participants were identified using athletic department employee directories or a database consisting of NCAA soccer coaches (contactcollegecoaches.com) from a total of 1043 different institutions. A total of 1860 men's and women's soccer programs are reported across the three NCAA divisions[147]. An email invitation detailing the purpose of the study, the qualification criteria for participants, and the intended benefits of the study was sent to each potential participant. If no response was received within the first two weeks of the initial invitation, a second email was sent. A third and final email was sent four weeks after the initial invitation if eligible participants did not respond. After six weeks, eligible participants who did not respond were assigned a "no response" classification. Consent and willingness to participate in this study were secured at the start of the Qualtrics survey prior to allowing participants access to the remainder of the survey.

Survey Design

The initial survey was produced by a sports scientist with three years work experience in collegiate soccer, a sports scientist with over ten years in NCAA athletics and two Kinesiology researchers with backgrounds in sport coaching and physical activity monitoring. The development of this survey used previous survey-design studies focusing on exploring practitioners' perceptions of performance monitoring themes (training load monitoring, and sports science)[15,16,64]. The survey was designed to capture (1) demographic and background information of practitioners (22 questions); (2) current program capabilities and practices of training load monitoring (10 questions 23-32); (3) training and practice planning (10 questions 33-42); (4) training load monitoring feedback (8 questions 43-50). Multiple choice and Likert scale questions were used. For some multiple choice questions, participants were asked to provide additional details to their answer in a free-response form. Likert scale questions contained five points and were fully labelled with response labels[148]. Response labels chosen represented constructs relevant to the themes investigated by this study (Levels of agreement, influence, responsibility, frequency, etc). Survey content validity was reviewed via a small cohort of coaches and a sports scientist working at the collegiate level. This process aided in modifying the survey to include, remove, or amend questions. The revised version of the survey (Table 1) was reviewed by the research team before final approval for circulation.

Table 1: Survey for Coaches and Sports Scientists in NCAA Soccer

Theme	Question #	Question							
Demographic	1	Which age group do you fall under?	20-30 years	31-40 years	41-50 years	51-60 years	>60 years		
	2	To which gender do you most identify?	Female	Male	Transgender Female	Transgender Male	Gender Variant/Non-Conforming	Not Listed	Prefer Not to Answer
	3	Which of the following best describes your current job title?	Head Coach of Soccer Program	Assistant Coach of Soccer Program	Sports Scientist	Strength and Conditioning Coach			
	4	How many years of experience do you have working within NCAA soccer?	0-1 years	2-3 years	4-5 years	6-10 years	>10 years		
	5	Which best describes who your role serves?	NCAA Men's Soccer Program	NCAA Women's Soccer Program	Both an NCAA Men's and Women's Soccer Program				
	6	What level do you coach at?	NCAA Div. I	NCAA Div. II	NCAA Div. III				
	7	Do you have playing experience in collegiate soccer?	Yes	No					
	8	What is the highest level of education you completed?	High School	Undergraduate Degree	Graduate Degree				
	9	Do you have a coaching license? If so, which best describes your license level?	No	Yes, D-License	Yes, C-License	Yes, B-License	Yes, A-License		

Table 1 (cont'd)

Sport Science	10	In order to measure your program's training, which of the following do you use (select all that apply)?	Questionnaires	Session Rating of Perceived Exertion (sRPE)	Heart Rate (HR) Monitors	Acceleromete r Technologies	GPS Technologie s	Video Time Motion Analysis	Other	Non e
	11	In order to measure your program's competitions, which of the following do you use (select all that apply)?	Questionnaires	Session Rating of Perceived Exertion (sRPE)	Heart Rate (HR) Monitors	Acceleromete r Technologies	GPS Technologie s	Time Motion Analysis	Other	Non e
Training Planning	12	Your program has someone who's responsibilities are committed to monitoring training	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree or Disagree	Somewhat Agree	Agree	Strongly Agree	
	13	Measuring training and competition provides information about performance	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree or Disagree	Somewhat Agree	Agree	Strongly Agree	
	14	Measuring training and competition provides information about fatigue	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree or Disagree	Somewhat Agree	Agree	Strongly Agree	
	15	Measuring training and competition provides information about fitness	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree or Disagree	Somewhat Agree	Agree	Strongly Agree	
	16	Who is responsible for planning practices training:								
	16a	Coaches	Not at all Responsible	Somewhat Responsible	Mostly Responsibl e	Fully Responsible				
	16b	Sports Scientists and/or Strength Conditioning Coach	Not at all Responsible	Somewhat Responsible	Mostly Responsibl e	Fully Responsible				
	17	Coaches should have:								
	17a	Knowledge of the scientific process of training in needed to plan a training week	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree or Disagree	Somewhat Agree	Agree	Strongly Agree	
	17b	Experience of the practical training environment to plan a training week	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree or Disagree	Somewhat Agree	Agree	Strongly Agree	
	18	Sports Scientists should have:								
	18a	Knowledge of the scientific process of training in needed to plan a training week	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree or Disagree	Somewhat Agree	Agree	Strongly Agree	
	18b	Experience of the practical training environment to plan a training week	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree or Disagree	Somewhat Agree	Agree	Strongly Agree	
	19	When planning training, what is the influence of:								
	19a	Current match schedule	Not at all Influential	Slightly Influential	Somewhat Influential	Very Influential	Extremely Influential			
	19b	Previous training	Not at all Influential	Slightly Influential	Somewhat Influential	Very Influential	Extremely Influential			
	19c	Time of Season	Not at all Influential	Slightly Influential	Somewhat Influential	Very Influential	Extremely Influential			
	19d	Player Fitness	Not at all Influential	Slightly Influential	Somewhat Influential	Very Influential	Extremely Influential			
	19e	Players own feelings	Not at all Influential	Slightly Influential	Somewhat Influential	Very Influential	Extremely Influential			

Table 1 (cont'd)

Training Load Practices	20	How frequently are individual player training sessions adjusted due to prior training load information?	Never	Rarely	Sometimes	Often	A Great Deal		
	21	How frequently are the teams' training sessions adjusted due to prior training load information?	Never	Rarely	Sometimes	Often	A Great Deal		
	22	Within your program, who is responsible for monitoring training load?	Head Coach	Assistant Coach	Sports Scientist	Strength and Conditioning Coach	Athletic Trainer		
	23	Within your program, who is responsible for the analysis and interpretation of training load data?	Head Coach	Assistant Coach	Sports Scientist	Strength and Conditioning Coach	Athletic Trainer		
	24	Within your program, who is the training load information prepared for?	Head Coach	Assistant Coach	Sports Scientist	Strength and Conditioning Coach	Athletic Trainer		
	25	There are clear objectives in the preparation of the training loads	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree or Disagree	Somewhat Agree	Agree	Strongly Agree
	26	Tactics are taken in consideration when preparing the training loads	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree or Disagree	Somewhat Agree	Agree	Strongly Agree
	27	The preparation of the training loads is collaborative amongst coaching staff, athletic performance staff, and athletic training staff	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree or Disagree	Somewhat Agree	Agree	Strongly Agree

Table 1 (cont'd)

Training Load Monitoring Usefulness and Feedback	28	Training load reports are produced reflecting _________ training loads:								
	28a	Daily	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree or Disagree	Somewhat Agree	Agree	Strongly Agree	
	28b	Weekly	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree or Disagree	Somewhat Agree	Agree	Strongly Agree	
	28c	Monthly	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree or Disagree	Somewhat Agree	Agree	Strongly Agree	
	28d	Annually	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree or Disagree	Somewhat Agree	Agree	Strongly Agree	
	29	Training load reports produced in a timely manner	Never	Rarely	Sometimes	Often	A Great Deal			
	30	Training load reports are communicated in a clear and practical manner	Never	Rarely	Sometimes	Often	A Great Deal			
	31	Your program has the expertise needed to properly monitor training loads	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree or Disagree	Somewhat Agree	Agree	Strongly Agree	
	32	Your program has the equipment needed to properly monitor training loads	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree or Disagree	Somewhat Agree	Agree	Strongly Agree	
	33	Your program uses this variable to assess training and competition (select all that apply):	Acceleration (Peak acceleration, Velocity Change Load)	Velocity (Average velocity, peak velocity)	Relative Speed (Time or Distance spent above a velocity threshold)	Heart Rate (Average heart rate, maximum heart rate, duration spent in heart rate zones)	Accelerometry (Player Load, IMAs, Changes of Direction, Jumps)	Metabolic Power (Average metabolic power, explosive distance)	Subjective (Rating of Perceived Extertion, Coach Observation)	Other (Total Distance, Total Duration)

Informed consent was provided on the first page of the online survey. Participants were asked to voluntarily sign the informed consent form and provide an email address before proceeding with the survey. Participants were allowed to type out their full name to provide a signature. A copy of the informed consent form was emailed to the participant using the provided email address.

The survey was distributed using Qualtrics via email. All email addresses (n=4996) were procured from an NCAA soccer coach database (contactcollegecoaches.com), from NSCA Special Interest Groups, or directly from athletic department websites. The email containing the survey briefly described the purpose of the survey and the intended outcomes. A link to the survey, which was made available online, was made provided in the email invitation. The survey was estimated by Qualtrics to take approximately 12 min to complete.

Data reduction and analysis

This survey was intended to be completed by individuals who managed the sports science responsibilities for an NCAA men's or women's soccer program. We anticipated that these responsibilities could be managed by a coach, strength and conditioning coach, sports scientist, athletic trainer, or another practitioner altogether. As a result, all participants were asked to identify which title best described their role so their responses could be analyzed respectively.

At the end of the survey completion period, all data were exported from Qualtrics for analysis. From the demographic data, we assessed the number of programs with sports scientists dedicated to the program and determined the percentage of programs using another practitioner to manage the training load monitoring and reporting aspects of sports science.

Likert scale data were treated as numeric values and assessed for normality using the Shapiro-Wilk's test and Q-Q plots. Data were presented as mean±SD (95% confidence intervals).

RESULTS

Respondents

A total of 370 surveys were completed yet only 187 were considered eligible practitioners to participate in this study (age = 37.9 ± 10.0 yr; NCAA experience = 12.5 ± 8.7 yr). Based on a total of 1043 institutions, we estimate a response rate of 17.9%, falling just below the 25-30% response rate typically reported for email surveys[149]. Notably, 26.5% of the total Division I institution responded, falling within the reportedly typical range for email surveys[149]. Fifty-one respondents identified as female, 134 as male, while 2 responded with 'prefer not to say'. While this study targeted practitioners who identified as being responsible for sports science, participants were asked to identify which capacity, sport coach, strength and conditioning coach, sports scientist, athletic trainer, or other practitioner, best reflected their current role. Based on this question, 128 of these practitioners identified as coaches (age = 40.6 ± 10.4 yr; NCAA experience = 14.0 ± 9.5 yr), 45 as strength and conditioning coaches (age = 31.4 ± 7.5 yr; NCAA experience = 9.5 ± 5.7 yr), 13 as sports scientists (age = 31.8 ± 4.6 yr; NCAA experience = 7.1 ± 4.9 yr), and 1 as other (age = 42.0 ± 0.0 yr; NCAA experience = 16.0 ± 0.0 yr). No participants identified as athletic trainers within ths study. The majority of coaches reported their highest completed education was a Master's Degree (53%) or an Undergraduate Degree (30%). Nearly 58% of strength and conditioning coaches reported their highest completed education was a Master's Degree. Approximately 23%, 54%, and 23% of sports scientists practitioners reported highest completed degrees of Undergraduate, Master's, and Doctoral Degrees, respectively.

Several survey questions were intended to investigate the programs these practitioners served. Most participants reported working with a women's soccer program (n = 106), while 67 worked with a men's soccer program and 12 worked with both a men's and women's soccer program (2 did not provide response). Of the 92 Division I soccer programs represented, 29 were from Power Five Football Bowl Subdivision (FBS) universities, 14 from Group of Five FBS universities, 49 from Football Championship Subdivision (FCS) universities; an additional 32 Division II and 62 Division III programs were represented by practitioners in the study. Further examination of noncoach practitioners revealed the majority of sports scientists and strength and conditioning coaches worked with NCAA Division I programs. More specifically, 9 of the sports scientists worked at the FBS level (Power Five = 8, Group of Five = 1), 2 at the FCS level.

Similarly, 21 strength and conditioning coaches worked at the FBS level (Power Five = 17, Group of Five = 4) and 21 at the FCS level. Only three noncoach practitioners worked with Division II programs while no noncoach practitioners worked with Division III programs.

A final, demographic component of this survey was to consider the background of coaches. Of the 128 coaches, 111 reported having a FIFA or U.S. Soccer Federation (USSF) Coaching License. Coaches reported being in their current role for an average of 11.35 ± 9.80 years. All reported personal playing experience of 22.58 ± 8.90 years and most played at the collegiate level. The coach respondents had an average of 19.35 ± 10.0 years of coaching experience.

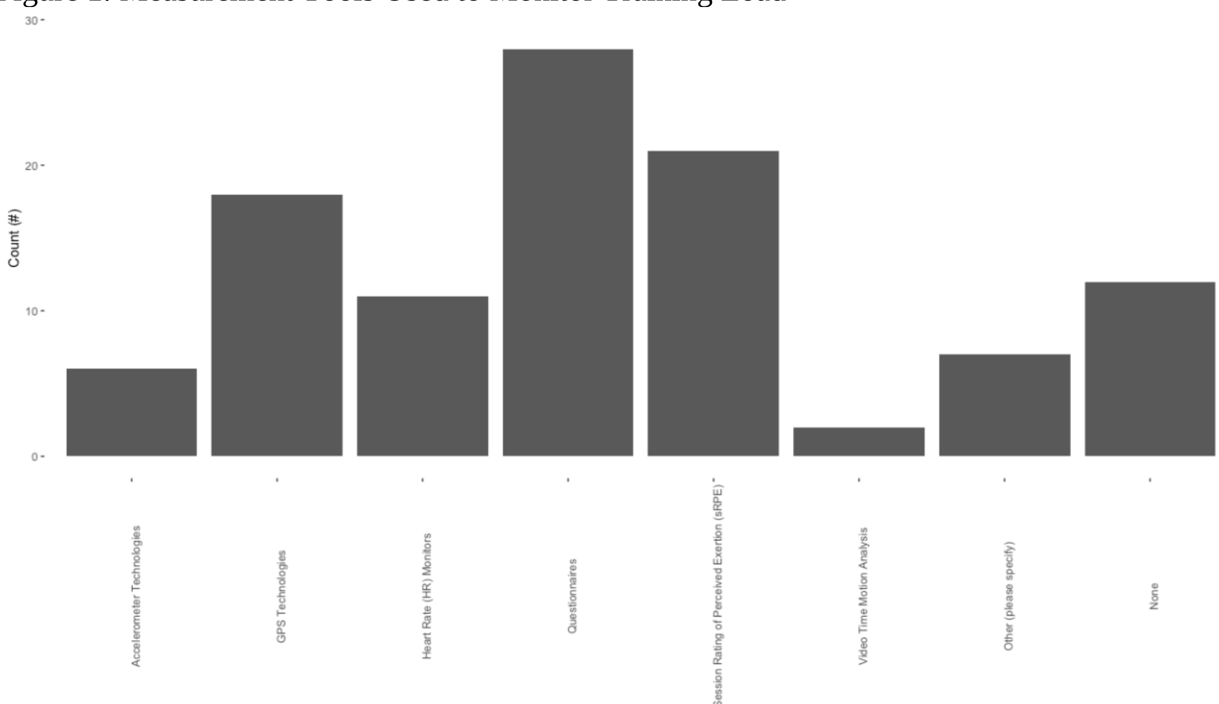
Training Planning

The majority of respondents reported that the head coach was ***most responsible*** for practice planning. Ten percent of respondents indicated that the assistant coach was ***most responsible*** for planning training. Sports scientists, strength and conditioning coaches, or other practitioners were not reported to be ***mostly responsible*** by any of the respondents. Respondents provided that current match schedule (4.51 ± 0.63) and player fitness (4.02 ± 0.83) were ***very important*** to planning practices. The previous training session (3.93 ± 0.85), time of season (3.04 ± 1.81), and player feelings (3.27 ± 0.90) were considered only ***moderately important*** by respondents to practice planning. Most respondents reported that they adjusted practice sessions for both, individuals and the team, ***about half the time*** (2.78 ± 1. 14; 2.59 ± 1. 16).

Training Load Practices

A breakdown of training load technologies reportedly used by the respondents' programs can be found in Figure 1. While a significant number of programs reported using some type of technology to monitor training loads throughout the season, a number of respondents provided that their program did not use any technologies as a result of budgetary limitations. Further examination of these responses showed that this response was only provided at the NCAA Division II, and Division III levels, not within Division I FBS or FCS programs. For programs that had access to monitoring technologies, 61.5% of respondents reported monitoring all players during all practices while 13.9% monitored a subset of players during all practices. The remainder of respondents stated they did not monitor players during practices. During matches, 59.9% of respondents reported monitoring all of their players, while 24.6% and 15.5% reported monitoring a subset of players or not monitoring players at all, respectively. For the purposes of this study, monitoring could refer to questionnaires, sRPE, HR monitoring, accelerometer technologies, GPS technologies, or video time motion analysis.

Figure 1: Measurement Tools Used to Monitor Training Load



Training Load Monitoring and Usefulness

To communicate training load monitoring, practitioners reported most commonly using verbal, informal conversations as a channel to communicate (62.6%). Other commonly used channels included documents (e.g. PDF, Word Doc; 51.9%), verbally during formal meetings (49.7%), and dashboards or electronic databases (49.7%). Several practitioners referenced the use of text messaging or email applications as another channel for communicating training loads (2.1%). Overall, practitioners seemed to employ multiple communication channels to update other members of the staff on training loads. Most practitioners reported communication of training loads on a daily basis (57.2%) or weekly basis (21.9%). Thirty respondents provided that they never report training loads.

Generally, participants indicated that training load communication was intended for recipients throughout the program. These recipients included practitioners in full-time roles working with the programs such as, head and assistant coaches (85.6%, 74.3%), athletic trainers (51.9%), strength and conditioning coaches (47.6%), sports scientists (12.8%), sports dietitians (4.3%), sports psychologists (1.6%), directors of operations (0.05%), and sports medicine doctors (0.05%). A number of practitioners (2.3%) also indicated that players were an intended participant of training load communications.

DISCUSSION

This study surveyed sports science practitioners with the intent of determining the perceptions and applications of the sports scientist role in NCAA soccer. Similar studies have been performed in professional soccer[15,16]. One study has examined NCAA coach perceptions of sports science through qualitative interviewing from a single NCAA Division I university[73]. This study represents the first to our knowledge to survey practitioners across all three divisions of the

NCAA working solely with men's and women's soccer. Overall, this study of NCAA soccer presents the coach as the practitioner most commonly responsible for monitoring and managing training loads and sports science applications for their respective programs. For instances where a noncoach practitioner responded, the practitioner often represented a Division I program. Despite the limited prevalence of a formal, sports science role, the use of training load monitoring was commonly used throughout teams to manage performance throughout a season.

Demographics

Within professional soccer, there are formalized sports scientist practitioner roles[16]. Individuals within these roles may hold titles such as sports scientist, fitness coach, or strength and conditioning coach and directly serve the club[16]. We extended survey participation invites to these practitioners as well as coaches, athletic trainers, or other practitioners suspecting that NCAA soccer programs have significantly less resources to support full-time sports scientists working directly with their programs. While our response rate for all NCAA programs was lower than ranges typically expected of email surveys[149], we observed acceptable response rates from Division I programs suggesting our results are representative of this level of soccer. Our results suggest that within the NCAA, a coaching staff-member is most often carrying out the responsibilities of monitoring and managing training load. Only 13 practitioners identified having these responsibilities and identified as a sports scientist. All came from the Division I level and the majority represented an FBS Power Five program. The majority of strength and conditioning coaches who identified having training load monitoring and management responsibilities also worked for Division I programs. Again, most strength and conditioning coaches worked with an FBS Power Five program. The majority representation of sports scientists and strength and conditioning coaches at the Division I level suggests Division I programs are more equipped to support the responsibilities of the role. Furthermore, the predominance of practitioners working in FBS Power Five programs over FBS Group of Five or FCS programs, levels distinguished by the university's football program, highlights greater stratification of resources within the Division I level. It is unclear from the results of this survey why the Division I level allows for more of these practitioners but it is reasonable to suggest that this level comes with additional financial resources and greater staffing to provide soccer programs with these practitioners.

The subset of practitioners who identified as sports scientists reported highest education levels of Master's Degrees (n = 6), Some Doctoral Degree completed (n = 1), and Doctoral Degree (n = 6). All sports scientist practitioners reported their highest education level degree concentrated on kinesiology fields such as exercise physiology and biomechanics. Most sports scientist practitioners also reported kinesiology field concentrations in kinesiology fields for undergraduate and Master's degrees. These observations highlight the selection for specific kinesiology backgrounds amongst practitioners within sports science roles. While the selection for kinesiology fields in sports science roles may contribute a strong expertise toward the development of athlete performance preparation, practioners from other fields may contribute leadership and expertise to sports science. Rothwell and colleagues (2020) present the contributions research methodology practitioners could make to improving how sports science is carried out. They elaborate that a department of methodology could conceptualize and structure unique training systems; interpret, communicate, and integrate theory and practice; and collaboratively design practice environments while guiding the development of athlete behaviors of performance[77]. Similarly, McCall and colleagues (2016) call for research and development practitioners to answer 'what, why, and how' questions to support sports science practitioners responsible for providing ‘yes/no’ answers for coaches[65]. Other studies highlight the need for practitioners with expertise in data science to carry out data management and analytics processes[150,151].

Training Planning

All participants reported training planning responsibilities fell to the head coach and/or assistant coaches. This finding was in agreement with Akenhead and Nassis (2016) and Weston (2018) which identified that coaches were most responsible for determining training loads and that coaches were mostly responsible for planning training while sports scientists were somewhat responsible, respectively[15,16]. The responses within this study did not find sports scientists to have any degree of responsibility for planning training yet several participants suggested all staff members collaborated or contributed feedback to training plan. While this response may reflect a dynamic within NCAA soccer where other practitioners have little responsibility for planning training, it is unclear whether a great presence of sports scientists at this level would shift responsibilities pertaining to training planning.

It is unsurprising that, regardless of professional or collegiate level, coaches are identified as being most responsible for planning training. This often reflects an emphasis on tactical and technical preparation by coaches during training sessions[15,152]. While other factors such as physical and psychological preparation are pertinent to soccer performance[153], it seems that the tactical and technical factors are more important to perform at a high level[154]. This study did not ask respondents to rank the priority of physical, tactical, technical, and psychological performance during the training planning process. Still, this study identified coaches to be most responsible for planning training across all three divisions of men’s and women’s soccer. Ford and colleages (2010) indicate that the coach’s primary role is to enhance skill acquisition for players to perform successfully during competition[155]. This often places an emphasis on technical and tactical preparation[152]. With the incorporation of sports scientists and strength and condititoning coaches at the Division I level, coaches remained most responsible for planning training. If sports scientists and strength and conditioning coaches are intended to manage the physical preparation and performance of players and are not identified to have significant responsibility for how training is planned, it may be argued that tactical and technical preparation remain the priorities within the NCAA soccer environment. Further study of how coaches plan seasons and training sessions and when different elements of performance are prioritized may improve how sports scientists can improve coach buy-in and incorporation of training load management strategies.

Unsurprisingly, practitioners within this study considered a number of aspects critical to the training planning process. Some differences between practitioners within this study and those surveyed in other studies were presented which may be reflective of how practitioners interpret different aspects (i.e. player fitness) subjectively. Weston (2018) found both coaches and practitioners agreed that the previous training session, time of season, player fitness, and players own feelings were somewhat influential in planning training. Practitioners identified that current match schedule was very influential to planning training while coaches identified this to be somewhat influential[16]. The majoriy of practitioners within this study generally identified that current schedule, previous training, time of season, and player fitness were very important to training planning. Only players feelings were considered moderately important. The practitioners within this study seemed to place greater importance on each of these aspects than the coaches and practioners within the Weston (2018) study. The sole exception was greater importance of player feelings by the coaches and practitioners in the Weston (2018) study. It is unclear why these differences are presented but differences between the two practitioner groups survey can be identified and lend some explanation. The coaches and practitioners surveyed within Weston (2018) worked with a wide range of age groups from youth- to professional-level English Football Association clubs. Practitioners within this study work only with collegiate-level soccer players. Differences in schedule congestion and season duration may influence how some of these factors are prioritized as NCAA soccer practioners must account for a denser match schedule within a shorter season[46]. Thorpe and colleagues (2017) highlight that the relationship between player feelings and performance, injury, and illness is unclear[156]. Perhaps, this is a reason practitioners within the NCAA are less willing to employ player feelings into how training is planned.

Program Training Load Practices

The results of this study highlight that most NCAA soccer programs use some type of monitoring tool throughout the season. The most commonly reported application of these tools is to inform about physical performance yet practioners indicated the applications also extend to tactical, technical, and mental performance domains. These performance domains were provided to explore how practitioners were examining overall soccer performance using different monitoring tools. Bangsbo (1994) originally presented a holistic model of soccer performance suggesting that physical, tactical, technical, and psychological capacities determined overall soccer performance[153]. Practitioner responses within this study maintain that each of these domains are pertinent to soccer performance although it is unclear how training load monitoring tools are being used to examine these domains. Further investigation into how these technologies are being used to measure these performance domains could provide additional insights into the value of these technologies.

A subset of practitioners within this study reported not using any type of monitoring tool within their program. Two commonly reported reasons for this were lack of financial resources and lack of human resources to manage these tools. The lack of financial resources was an unsurprising reason for not monitoring training loads yet may also reflect a lack of understanding amongst practitioners for what training load is and how readily it may be captured. It is plausible that practitioners who reported lack of financial resources being the reason for not monitoring training load identify this practice requires the purchase and use of technologies like GPS, accelerometers, or heart rate monitors. While these are commonly employed technologies[15,16], other methods such as sRPE and wellness questionnaires require no equipment purchase and may capture training loads throughout the season[152,157,158].

Insufficient human resources was also reported by professional soccer practioners as a limitation to carrying out training load monitoring[15]. Akenhead and Nassis (2016) recommend involving universities and interns to mitigate this limitation for professional soccer clubs[15]. It seems the same partnerships could be made at the NCAA soccer level provided program's established affiliations with the universities they represent. Programs could consider employing student interns and academic partnerships to carry out the day-to-day management of training load monitoring and improve the interpretation of training load data. The responses within this study reflect this is not occurring often although one practitioner provided that they were a university professor consulting with the team. Similar partnerships may stimulate growth for sports science within the NCAA soccer landscape while providing research opportunities for professors and students.

Training Load Monitoring: Modes and Recipients of Training Load Communication

Regarding the communication of training load information, we observed that practitioners most commonly relied on verbal, informal conversations with other practitioners. While coaches represented the primary recipient of this information, other practitioners were included as recipients. Bourdon and colleagues (2017) come to the consensus that training load monitoring information should be provided to coaches to assist and inform player availability[157]. Yet, Bartlett and Drust (2020) highlight the web of communication extends from sports scientists to a number of stakeholders beyond the coach including: athletes, operations, scouting, doctors, physical therapists, massage therapists, athletic trainers, strength and condititioning coaches, dietitians, performance analysts, and welfare professionals in professional sporting environments[8]. Although many college athletic programs may not be afforded the human and financial resources of professional sports organizations, there are some key stakeholders who are less frequently identified as recipients of training load information compared to coaches. This may be cause for concern. Athletic trainers, for instance, serve NCAA programs across all levels and are responsible for the diagnosis, management, and return-to-play determinations for all student-athletes[159]. Training load information can inform how athletes are responding to training throughout the return-to-play process[160]. Practitioners, in this case athletic trainers, are encouraged to plan training loads for specific to individual athletes during the return-to-play process[161]. If, however, these practitioners are not included in the regular reporting of training loads, they may become uninformed about how the athletes are responding to training and inadequately return the athlete to play. The delivery of training load information should extend to the entire high performance team at the NCAA level to ensure each practitioner is informed on the training status of players throughout the season and may carry out their responsibilities related to training accordingly. Future study should consider how training load information is extended to high performance teams differently when a sports scientist is on staff.

The group rarely mentioned by practitioners in this study as a recipient of training load information and yet present in all NCAA programs is the athlete. Bourdon and colleagues advise practitioners to provide training load information and feedback to players as well as coaches[157]. Le Meur and Torres (2019) emphasize that the provision of individualized information and feedback will maximize athletes' buy-in to sports science[7]. Only six programs mentioned communicating training load information to players, and it remains unclear what type of information is provided to the athlete. Practitioners are recommended to provide eye-catching, easy-to-digest visual reports to athletes[7]. In a recent survey by FIFPRO (2022), a World Players' Union for professional soccer players, over 80% of players still report wanting access to their performance data. Furthermore, players reported being unclear about how their data are being collected and used[162]. It would be reasonable to suggest that similar patterns are being observed at the NCAA soccer level provided how few responses indicated the athlete as a recipient of training load information. Practitioners carrying out training load monitoring should consider how they are educating and informing the athlete on training load throughout the season as the monitoring occurs.

The favortism towards informal, verbal conversations appears to reflect the 'thinking fast' dynamic presented by Kahneman (2011) and later applied to sports by Coutts (2016)[58,163]. Informal, verbal conversation allows practitioners to lean into speed, intuition, and emotion to drive decisions as opposed to using slower, deliberate, and logical modalities which tend to be more reflective of formal research scientists[58]. This pattern was congruent with the reported research disseminations preferred by sports science practitioners which included one-on-one conversations and infographics[59]. Provided the rate at which decisions must be made in sports, practitioners must focus on making training load information available quickly and clearly[16]. This requires practitioners to be time-efficient and effective in analyzing and delivering information[7]. About half of participants in this study reported using some type of dashboard or electronic database to deliver training load information. Future studies may consider what information sports science practitioners identify is most pertinent to other practitioners on a training load report to improve the efficiency and delivery of training load information.

CONCLUSION

The purpose of this study was to examine who was carrying out sports science, specifically training load management, and how this was carried out in the NCAA soccer environment. To our knowledge, this was the first study examining the roles and responsibilities related to sports science in NCAA soccer. Overall, this study presents coaches as the stakeholder most frequently responsible for the management of training loads and the communication throughout an NCAA soccer program. While other practitioners, such as strength and conditioning coaches and sports scientists are being introduced in NCAA soccer programs to hold these responsibilities, resources and trainings about training load monitoring and management should target coaches as the primary audience until a shift in responsibilities is observed.

CHAPTER 4: FACTORS AFFECTING TRAINING LOADS DURING THE NCAA SOCCER MICROCYCLE: SPECIAL REFERENCE TO PROGRAM AND PLAYER ROLE

ABSTRACT

Approximately fifty thousand student-athletes compete in NCAA Men's and Women's soccer. The NCAA season presents unique challenges to the sport with a shortened, more congested season. Many programs are using training load monitoring as a tool to manage performance and recovery yet it is unclear how training loads are typically distributed at this level throughout a team. As a result, the purpose of this study is to identify the distribution of training loads throughout the in-season NCAA men's and women's soccer microcycle, paying special attention to player roles (starters, substitutes, and bench players). Soccer field players from an NCAA Division I program were monitored throughout the Fall 2021 season for all training sessions and matches using a GPS and accelerometer system. Players from each program were categorized into bench, substitute, and starter based on average duration of minutes played in matches throughout the season. Days throughout each microcycle were classified according to the number of days before match day. Linear mixed effect modelling was performed to determine the effects of player role and day of microcycle on the outcome variables (total distance, high-speed running distance, sprint distance, medium and high intensity acceleration and decrelation counts). Results of the study demonstrated that match day elicited the greatest training loads while the day prior to the match (MD-1) presented the lowest. Throughout the season, starters accumulated greater training loads than substitutes and bench players for all measures except total sprint distance. Comparing the men's and women's programs, total playerload and medium- and high-intensity accelerations and decelerations were significantly greater amongst the men. These findings demonstrate that most training load is developed on match day by starters, presenting substitutes and bench players with lower training loads throughout the season. Sports science practitioners should consider how much supplemental

training load should be provided during training to prepare these players for starter match demands.

INTRODUCTION

In its most recent participation report, the National Collegiate Athletics Association identified that over fifty thousand student-athletes compete at the Division I, II, and III levels in Men's and Women's soccer[164]. This level of competition serves as a valuable intermediary level between the youth and professional levels of soccer while developing athletes' physical, technical, and tactical skills. While similarities between the NCAA and professional levels exist (e.g., size of the ball, dimensions of the pitch, number of players on the field, duration of the match), there are some critical differences related to the duration and congestion of the season.

The NCAA Championship season spans August to early-December during which teams play 3 exhibition and 18 regular season matches before competing in conference and national tournaments. This schedule can elicit over 25 matches in a 15-week season, which occasionally has three matches during a week[46]. To account for this schedule, coaches and performance practitioners must be conscious of their athletes' stress, fatigue, and recovery throughout the season.

Training load monitoring represents one way to manage the stress, fatigue, and recovery of athletes to ensure optimal match-day performance and recovery[17,129]. Training load can be considered external, the work performed by an athlete, and internal, the physiological and psychological stress place on the athlete by the work performed[17]. External training loads are often assessed in soccer using time-motion analysis to provide measures of volume and intensity [17,42,129,132–134]. For professional soccer, training loads are often contextualized by the microcycle or the period of time between matches. Oliva-Lozano and colleagues (2021) describe short microcycles, regular microcycles, and long microcycles in professional soccer which include 5- or 6-day, 7-day, and 8- or 9-day time periods between matches, respectively[133]. This is significantly longer than the 3- to 5-day microcycles experienced in NCAA men's and women's soccer and represents one the effects of the NCAA season on training[42].

Unsurprisingly, training loads throughout the microcycle vary from day to day. Each day throughout the microcycle can be characterized based on the number of days until the upcoming match (e.g., MD-1 is one day before the match, MD+1 is one day after the match)[18].Training loads for one study of Spanish La Liga men's players were greatest in intensity and volume for training sessions MD-3 and MD-4 or MD+1[133]. A similar trend was observed in an EPL men's team which covered greater distances on MD-3 compared to MD-2 and MD-1 during a 1- and 2-match per week schedule[129]. Amongst five NCAA Division I men's teams, total distance and high-speed run distance were significantly greater on the MD-2, MD-3, MD-4, and MD-5 compared to MD-1. Only training days more than 5-days out from the next match were significantly different from any of the other training days[42]. Generally, these studies suggest that as teams approach matches, coaches tend to reduce the training load volume.

In addition to the differences between the duration of microcycles, NCAA soccer presents substitution rules unique to those observed in professional soccer. Specifically, the NCAA allows significantly more substitutions during a match than professional soccer[43]. Players are also allowed to reenter the match a limited number of times at the college level[43]. At the professional level, players may be categorized as starters, fringe, and non-starters according to the number of games started throughout the season[33]. Starters represent players who regularly start matches; fringe represents players who occasionally start, and non-starters represent players who do not start. These role differences are important, as starters are anticipated to play more minutes during a match and consequently, accumulate greater training loads throughout competitive phases of the season. At the NCAA level, characterizing players similarly may not elicit similar results as more players can be used and substituted throughout a match. Practitioners may benefit from categorizing their players as starters, substitutes, and bench players where starters play the greatest minutes, substitutes regularly play some but limited minutes, and bench players rarely see playing time throughout the season in order to adjust training loads accordingly. Such characterizations have been used to describe player roles in basketball, a sport that also has looser substitution rules than professional soccer[165]. Characterizing players according to roles becomes important as sports scientists and coaches manage individual training loads within players. In their study of men's professional soccer training loads, Anderson and colleagues determined that fringe and non-starters accumulate significantly less running volumes than starters throughout entire seasons, suggesting that these players may experience de-training and increased injury risk as result of their playing status[33]. It is unclear whether a similar trend would be observed in NCAA soccer provided these substitution rules.

A significant concern for the growth of research in sports science and training load management throughout the microcycle is that it has not extended to women's soccer as much as men's soccer. Several studies examine the match demands of women's collegiate soccer[47,166] or the demands of soccer practices[131] but more research profiling the demands of the sport in training and competition relative to player roles in the women's collegiate and elite-level is needed. As a result, this study's purpose was to identify the distribution of training load throughout the in-season NCAA men's and women's soccer microcycle, focusing on differences amongst player roles (starters, substitutes, and bench players). We expected training loads would be similar amongst men's and women's soccer players, greater for players who hold a starter role than players who hold a bench role, and similar for all three roles of players on training days.

METHODS

Participants

NCAA Division I soccer field players (i.e., no goalies) from one Men's team (n = 23, age = 18-23 yr) and one Women's team (n = 24, age = 18-23 yr) were included in this study from the Fall 2021 season. Training and match data were collected by each program's performance staff. The use of players' training and match data for the study was deemed exempt by the Institutional Review Board of Michigan State University.

Design

Training load data were collected for field players using a 10-GHz GPS and accelerometer system (Catapult Sports, Melbourne, Australia), which players wore in a compression garment for all team training and match activities. Players wore the same device throughout the duration of the study period. The Fall 2021 season included a preseason, regular season, and conference tournament season spanning from August to November. All training sessions and matches, home and away, were recorded and analyzed by the teams' sports scientist. A total of 55 activities were recorded by the men's program (17 matches) while a total of 53 activities were recorded by the women's program (18 matches). This provided a total of 2299 individual activities recorded, 93 individual activities were recorded in an indoor facility which inhibited the use of GPS measures (distance, acceleration, deceleration). All other measures (total duration, total player load) were recorded on these days.

The entirety of training sessions, including pre-practice free play, warm up, technical drills, passing drills, small- and large-sided play with or without goalkeepers, tactical games, finishing drills, and conditioning drills were recorded for the entire team. For several training sessions, training took place in an indoor facility. For these activities, GPS measures could not be acquired and therefore, were reported missing (men: n = 3; women: n = 2); however, total duration was recorded while the devices provided a total playerload measure from accelerometer data. On match day, warm up (approximately 30-minutes), both halves (approximately 45-minutes), and the halftime warm up (approximately 15-min) periods were recorded to determine all training load accumulated on a match day. Players were excluded from activity if they were not present or determined unable to participate per the team's athletic training staff.

Players (men: n=23; women: n=24) were characterized as bench, substitution, or starter at the end of the season based on the average duration they played in competition. This characterization has been implemented in other sports with similar substitution rules[165]. Starters included all players who averaged more than 100-minutes of on-field activity on match days. Twelve players from the men's program were characterized as starters while 9 players from the women's program were characterized accordingly. These players typically started the match and accumulated the highest tertile of playing time. Substitutes included players who average less than 100-minutes but greater than 65-minutes of on-field activity on match days. The men's and women's programs had 6 and 8 substitutes players respectively. These players typically did not start the match but were substituted into the match and therefore accumulated moderate playing time throughout the season. Bench players included all players who recorded less than 65-minutes of on-field activity on match days. Each program had 6 players who were charactized as bench players. These players accumulated the lowest tertile of playing time throughout the season and were rarely utilized during matches.

Each team competed at the NCAA Division I level and within the Big Ten Conference. As a result, both teams were expected to adhere to the NCAA's scheduling rules while fulfilling additional schedule requirements expected from the Big Ten Conference. Consequently, teams played 1- to 3-matches per week interspersing NCAA required off days into each week. To qualify as an off day, no activities could be scheduled for the entire team meaning no formal, additional training could be required for substitution and bench players, as reported in other micro-cycle studies[27]. Any training completed individually by these players was not measured. These schedule requirements produced a variety of micro-cycles with the number of days between competition ranging from 1- to 6-days. The two teams had highly inconsistent match and training schedules that provided a range of micro-cycles, however, the most often occurring micro-cycle provided one off day and two training days before a match. To account for the variety of micro-cycles, each training session was classified according to the number of days before match day (i.e., MD-1, MD-2)[18]. If training occured the day before a match, the session was tagged as MD-1. Microcycles varied from one full day of training preceding a match to more than four full days of training preceding a match (Training Days x Match: 1 x 1, 1 x 2, 1 x 3, 1 x ≥4). The frequency of these days is are shown in Table 2. In the event that there were more than three days of training prior to a match (ie., MD-4), the days > 3 out from the next match were removed from analysis, as teams typically tried to simulate an additional 1 x 3 microcycle by incorporating a scrimmage.

Table 2: Frequency of Days Relative to Match

Day	Men	Women
MD	17	18
MD-1	13	15
MD-2	13	16
MD-3	10	4

Data Collection and Analysis

Each player's physical performance was measured during training and matches using Catapult Vector units (Catapult Vector, Catapult Sports, Melbourne, Australia). Each unit measures activity at 10-GHz using GPS. The reliability of these devices has been reported as suitable and consistent for monitoring in field sports[167].

The following variables were selected for analysis: training total duration (min), total player load (AU), total distance (m), high-speed running distance (m; men: 19.8 km•h^{-1}, women: 19.0 km•h^{-1}), sprint distance (m; men: 25.2 km•h^{-1}, women: 22.5 km•h^{-1}), medium and high intensity acceleration and deceleration counts (HI-ACC: > 3.0 m•s^{-2}, Med-ACC: 2.0 to 3.0 m•s^{-2}, Hi-DEC: < - 3.0 m•s^{-2}, Med-DEC: -3.0 to -2.0 m•s^{-2})[35,51,94]. A minimum duration of 0.5s was required to qualify an accelerations or decelerations as a count.

Statistics

Statistical analyses were performed in R (R Core Team, 2022). Descriptive statistics were performed. An Initial Data Analysis (IDA) plan was applied to screen the longitudinal data prior to further analyes[168]. Missing data were considered missing at random meaning that no patterns for missing data could be determined and were reported as a percentage. All missing data were removed from the analyses using pairwise deletion[169]. Linear mixed effect modelling was performed using the *lmer* package to deal with unbalanced design, repeated measures, and missing data[170]. Individual models were created for each of the training load variables. Total duration, total playerload, total distance, high-speed running distance, sprint distance, medium- and high-intensity acceleration and deceleration counts which were each entered as the dependent variable for the respective model. Profile plotting performed as part of the IDA supported the inclusion of the date (converted to numerical day of season) and individual athlete as random effects.

Full models were composed to include all hypothesized main and random effects. For each full model, program was entered as an independent variable to evaluate differences between the men's and women's program and address our first hypothesis. Day, grouped by MD minus (i.e., days prior to upcoming match), was also entered as an independent variable to examine differences in training loads across days. Finally, role was entered as an independent variable to consider differences in training loads amongst the three roles, starters, substitutes, and bench, evaluating our hypothesis that training loads would be greatest amongst starters. Player ID and Date of training sessions were included as random effects to account for individual differences in training loads which were captured daily throughout the season in respect to each player. The full model was reduced using the *lmerTest::step* function which performs stepwise model selection using AIC. A summary of the reduced model for each outcome variable is provided in Tables 5-11, providing main and random effects. Significance was set at $p < 0.05$ *a priori*. Post-hoc analyses were performed using the *emmeans* package to provide model contrasts for each of the main effects.

RESULTS

Interday Differences of Training

Table 4 provides descriptive statistics for training load measures across the microcycle respective to the men's and women's programs. Figure 2 and Figure 3 present the training loads as a percentage of average match-day training loads anticipated of the starter group for each program. For both programs, MD training loads elicited greater training loads than the other days within the microcycle. Comparing the three training days during the microcycle, MD-1 typically presented the lowest training loads however, significant effects were only observed for total playerload, medium and high acceleration efforts, and high deceleration efforts. MD-2 appeared to present higher training loads for all measures compared to the other training days however training load differences were typically insignificant. Only total distance was significantly higher on MD-2 than both MD-1 and MD-3 throughout the season.

Figure 2: Comparing Training Loads Each Day in Women's Program

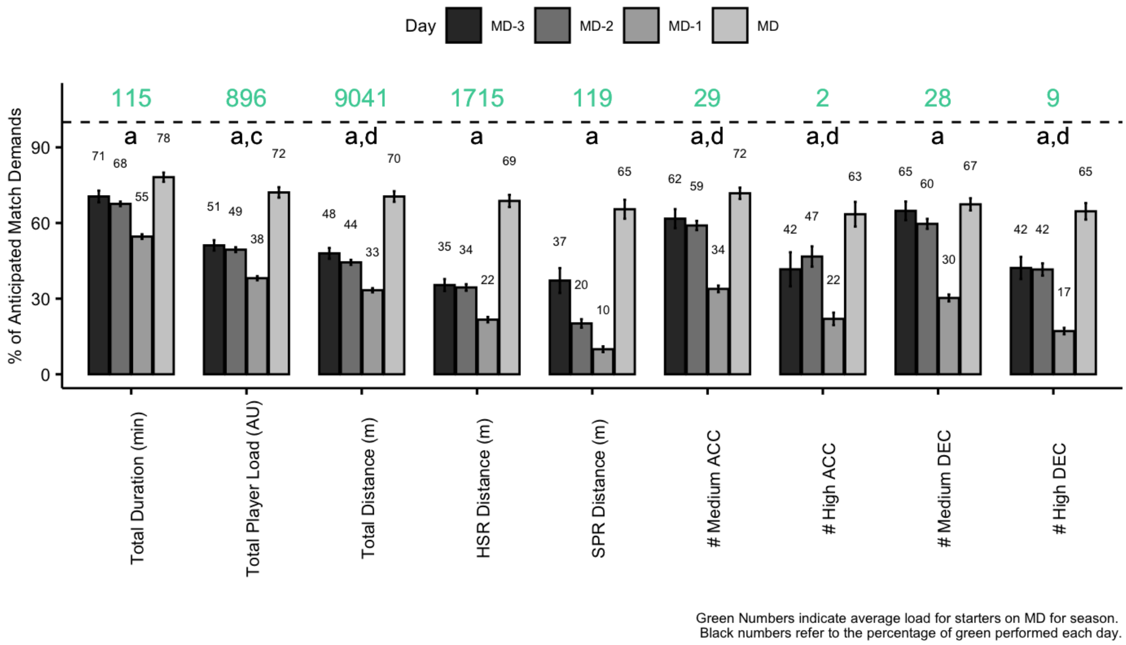
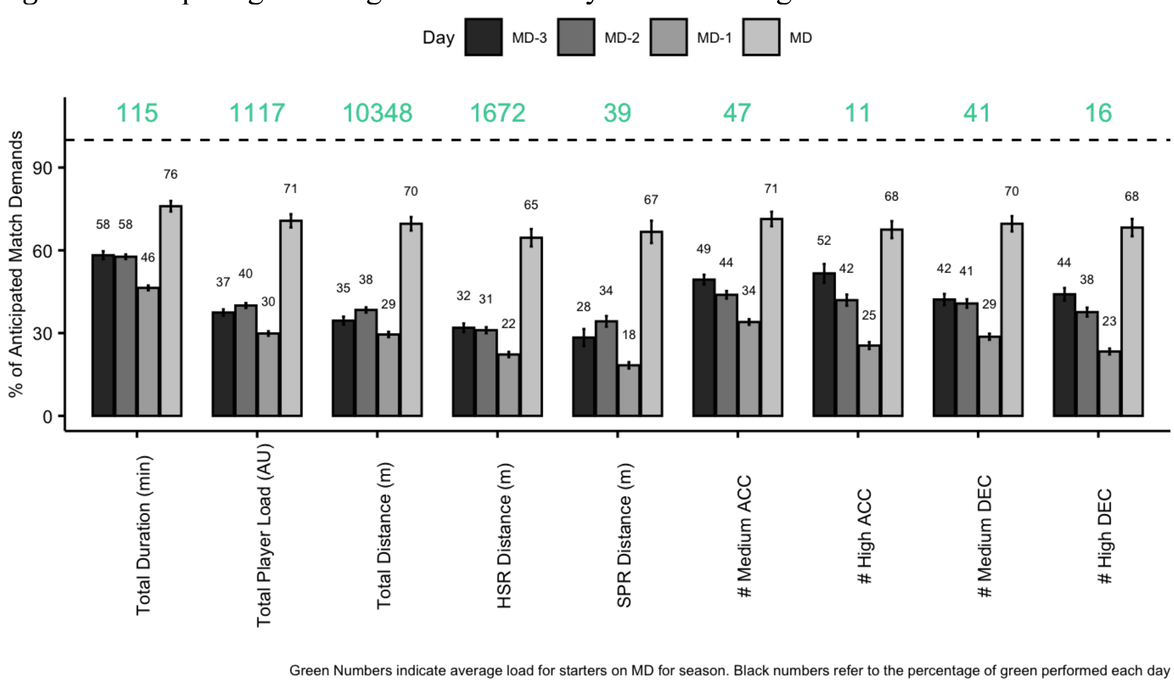


Figure 3: Comparing Training Loads Each Day in Men's Program



Training Differences amongst Player Roles

The distribution of player roles within the two programs is presented in Table 4. This table also provides the number of activities recorded by each of these roles throughout the season. The linear mixed effect models (Tables 5-13) present that substitutes and bench players had significantly lower training loads for all measures except total sprint distance throughout the season. Bench players had lower sprint distances throughout the season compared to starters. Although substitutes averaged greater sprint distance, medium and high intensity accelerations and decelerations per session throughout the season than bench players, these differences were non-significant. Contrasts revealed significant differences between substitution and bench players for total duration, total distance, total player load, high speed running.

Exclusive to the women's program, substitution players did not demonstrate significantly different training loads except for sprint distance, high-intensity accelerations throughout the season. The women's bench players demonstrated significantly less training loads for the sprint distance, medium and high intensity accelerations, and medium and high intensity decelerations.

Table 3: Number of Activities Recorded per Day and Role within each Program

	MSOC			WSOC		
	Starter (n = 12)	Substitute (n = 6)	Bench (n = 6)	Starter (n = 9)	Substitute (n = 8)	Bench (n = 6)
MD	142	117	89	213	104	94
MD-1	119	100	74	175	89	80
MD-2	114	94	78	156	93	92
MD-3	66	64	54	48	22	22

MSOC: Men's Soccer Program; WSOC: Women's Soccer Program, MD: Match Day; MD-1: Match Day Minus One; MD-2: Match Day Minus Two; MD-3: Match Day Minus Three

Differences between Programs

To account for differences between the men's and women's programs, each training load measure included program as a fixed effect. The training load measures of total duration and total distance covered were similar between the two programs throughout the seasons. HSR and SPR distances covered were statistically greater amongst women's players compared to the men's players. Meanwhile, total playerload, medium- and high-intensity accelerations and decelerations were significantly greater amongst the men's players.

Table 4: Description of Training Loads

	MSOC MD (N=348)	MSOC MD-1 (N=293)	MSOC MD-2 (N=286)	MSOC MD-3 (N=184)	WSOC MD (N=411)	WSOC MD-1 (N=344)	WSOC MD-2 (N=341)	WSOC MD-3 (N=92)	Overall (N=2299)
Total Duration (min)									
Mean (SD)	87.7 (41.4)	53.5 (17.2)	66.6 (16.4)	67.2 (22.7)	90.1 (42.7)	63.0 (19.8)	77.9 (19.3)	81.3 (25.7)	74.1 (31.6)
Median [Min, Max]	75.9 [1.50, 180]	55.6 [18.5, 173]	65.0 [13.6, 140]	60.0 [2.10, 152]	95.2 [22.1, 168]	61.9 [14.8, 146]	83.1 [18.4, 146]	83.4 [20.1, 141]	66.6 [1.50, 180]
Total Player Load (AU)									
Mean (SD)	790 (503)	333 (155)	447 (171)	418 (175)	646 (377)	341 (134)	443 (160)	458 (177)	502 (325)
Median [Min, Max]	688 [0.901, 2170]	322 [21.0, 1480]	440 [3.18, 1270]	380 [0.190, 1460]	648 [4.40, 1670]	331 [9.27, 1180]	449 [2.59, 1250]	471 [113, 1040]	405 [0.190, 2170]
Total Distance (m)									
Mean (SD)	7200 (4730)	3050 (1670)	3970 (1660)	3570 (1890)	6370 (3850)	3010 (1350)	4010 (1590)	4340 (1870)	4660 (3240)
Median [Min, Max]	6220 [1.38, 18700]	2910 [258, 16100]	3880 [499, 13800]	3260 [26.2, 15100]	6360 [8.22, 16400]	2860 [4.38, 12800]	4030 [0.193, 13200]	4560 [980, 11800]	3600 [0.193, 18700]
Missing	1 (0.3%)	17 (5.8%)	3 (1.0%)	24 (13.0%)	1 (0.2%)	24 (7.0%)	23 (6.7%)	0 (0%)	93 (4.0%)
HSR (m)									
Mean (SD)	1080 (981)	372 (265)	519 (313)	534 (332)	1180 (842)	372 (325)	591 (400)	607 (390)	705 (677)
Median [Min, Max]	902 [0, 4100]	326 [0, 2490]	505 [0, 2300]	496 [0, 2690]	1190 [0, 3670]	290 [0, 2640]	529 [0, 2570]	578 [12.6, 1980]	466 [0, 4100]
Missing	1 (0.3%)	17 (5.8%)	3 (1.0%)	24 (13.0%)	1 (0.2%)	24 (7.0%)	23 (6.7%)	0 (0%)	93 (4.0%)
SPR (m)									
Mean (SD)	25.9 (29.2)	7.10 (7.44)	13.3 (12.6)	11.0 (15.2)	78.0 (90.5)	11.8 (24.5)	24.0 (35.9)	44.3 (56.4)	29.0 (52.2)
Median [Min, Max]	15.5 [0, 182]	5.54 [0, 46.2]	11.5 [0, 83.1]	4.69 [0, 82.3]	47.7 [0, 480]	0 [0, 248]	7.97 [0, 241]	16.8 [0, 219]	9.17 [0, 480]
Missing	1 (0.3%)	17 (5.8%)	3 (1.0%)	24 (13.0%)	1 (0.2%)	24 (7.0%)	23 (6.7%)	0 (0%)	93 (4.0%)

Table 4 (cont'd)

MI Acceleration Efforts (#)									
Mean (SD)	33.7 (23.1)	16.1 (8.01)	20.8 (10.9)	23.4 (10.7)	20.6 (13.0)	9.74 (6.71)	17.0 (9.38)	17.8 (10.4)	20.1 (14.8)
Median [Min, Max]	30.0 [0, 123]	15.0 [0, 52.0]	20.0 [0, 61.0]	23.0 [0, 65.0]	18.0 [0, 72.0]	8.00 [0, 44.0]	15.5 [0, 55.0]	17.5 [0, 43.0]	17.0 [0, 123]
Missing	1 (0.3%)	17 (5.8%)	3 (1.0%)	24 (13.0%)	1 (0.2%)	24 (7.0%)	23 (6.7%)	0 (0%)	93 (4.0%)
HI Acceleration Efforts (#)									
Mean (SD)	7.35 (6.25)	2.78 (2.26)	4.57 (3.73)	5.63 (4.71)	1.21 (1.89)	0.419 (0.845)	0.890 (1.37)	0.793 (1.24)	2.95 (4.18)
Median [Min, Max]	5.00 [0, 29.0]	2.00 [0, 12.0]	4.00 [0, 27.0]	4.50 [0, 22.0]	0 [0, 12.0]	0 [0, 5.00]	0 [0, 8.00]	0 [0, 5.00]	1.00 [0, 29.0]
Missing	1 (0.3%)	17 (5.8%)	3 (1.0%)	24 (13.0%)	1 (0.2%)	24 (7.0%)	23 (6.7%)	0 (0%)	93 (4.0%)
MI Deceleration Efforts (#)									
Mean (SD)	28.8 (21.4)	11.9 (7.61)	16.8 (10.7)	17.4 (10.6)	18.9 (13.6)	8.47 (6.84)	16.7 (9.91)	18.1 (9.95)	17.3 (14.1)
Median [Min, Max]	25.0 [0, 90.0]	11.0 [0, 60.0]	15.0 [0, 67.0]	15.0 [0, 66.0]	18.0 [0, 51.0]	7.00 [0, 44.0]	16.0 [0, 53.0]	19.5 [0, 51.0]	14.0 [0, 90.0]
Missing	1 (0.3%)	17 (5.8%)	3 (1.0%)	24 (13.0%)	1 (0.2%)	24 (7.0%)	23 (6.7%)	0 (0%)	93 (4.0%)
HI Deceleration Efforts (#)									
Mean (SD)	11.1 (9.55)	3.80 (2.91)	6.13 (4.46)	7.18 (4.70)	5.51 (5.66)	1.46 (1.95)	3.55 (3.71)	3.60 (3.61)	5.43 (6.10)
Median [Min, Max]	9.00 [0, 42.0]	3.00 [0, 20.0]	5.00 [0, 24.0]	7.00 [0, 24.0]	4.00 [0, 32.0]	1.00 [0, 15.0]	3.00 [0, 23.0]	3.00 [0, 19.0]	3.50 [0, 42.0]
Missing	1 (0.3%)	17 (5.8%)	3 (1.0%)	24 (13.0%)	1 (0.2%)	24 (7.0%)	23 (6.7%)	0 (0%)	93 (4.0%)

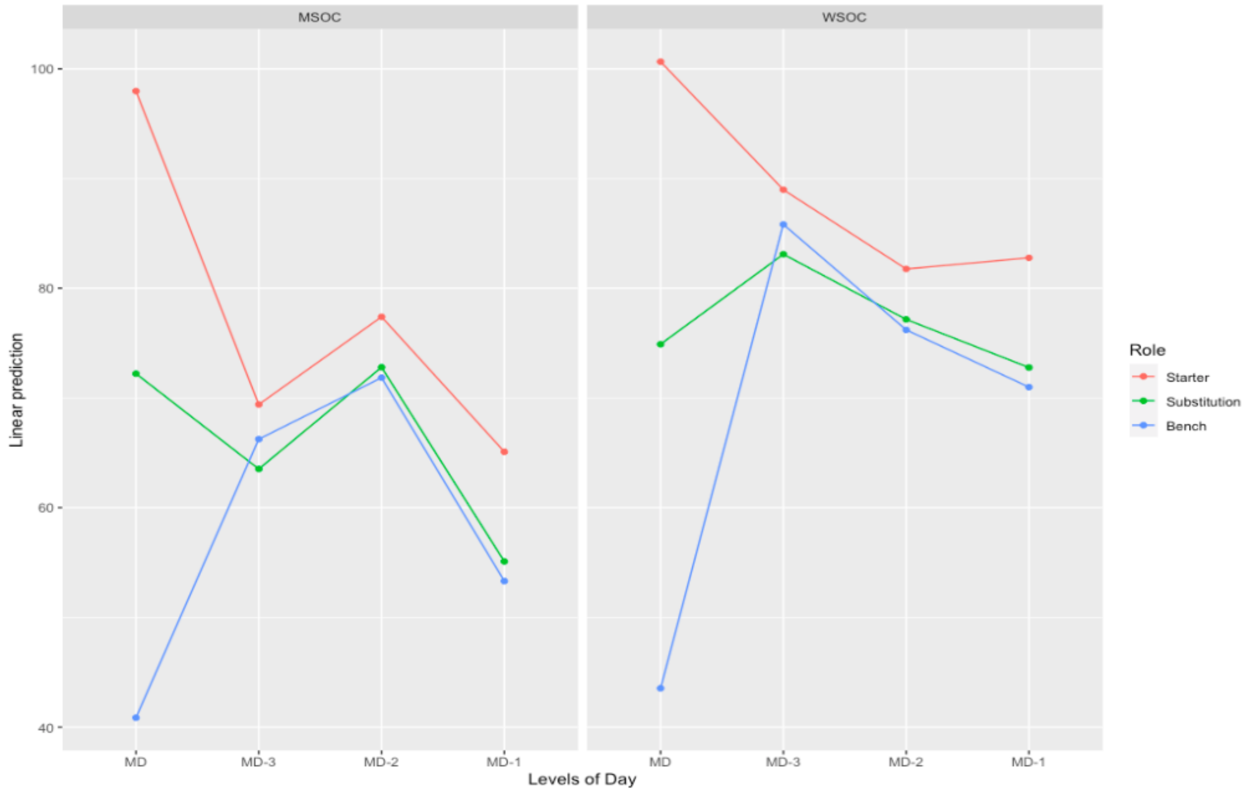
MSOC: Men's Soccer Program; WSOC: Women's Soccer Program; MD: Match Day; MD-1: Match Day Minus One; MD-2: Match Day Minus Two; MD-3: Match Day Minus Three

Table 5: Mixed Effect Model Results for Total Duration

	Total Duration							
Predictors	*Estimates*	*std. Beta*	*CI*	*standardized CI*	*p*	*std. p*	*df*
(Intercept)	40.86 ***	-1.05	35.69 – 46.02	-1.22 – -0.89	**<0.001**	**<0.001**	2275.00
Program [WSOC]	2.68	0.08	-1.49 – 6.85	-0.05 – 0.22	0.207	0.207	2275.00
Role [Starter]	57.11 ***	1.81	51.42 – 62.81	1.63 – 1.99	**<0.001**	**<0.001**	2275.00
Role [Substitution]	31.36 ***	0.99	26.78 – 35.94	0.85 – 1.14	**<0.001**	**<0.001**	2275.00
DayMD-1	12.45 ***	0.39	6.34 – 18.56	0.20 – 0.59	**<0.001**	**<0.001**	2275.00
DayMD-2	30.99 ***	0.98	24.99 – 36.99	0.79 – 1.17	**<0.001**	**<0.001**	2275.00
DayMD-3	25.38 ***	0.80	18.13 – 32.64	0.57 – 1.03	**<0.001**	**<0.001**	2275.00
ProgramWSOC:DayMD-1	15.00 ***	0.47	9.27 – 20.72	0.29 – 0.66	**<0.001**	**<0.001**	2275.00
ProgramWSOC:DayMD-2	1.68	0.05	-4.01 – 7.37	-0.13 – 0.23	0.562	0.562	2275.00
ProgramWSOC:DayMD-3	16.90 ***	0.53	9.25 – 24.54	0.29 – 0.78	**<0.001**	**<0.001**	2275.00
RoleStarter:DayMD-1	-45.33 ***	-1.44	-51.73 – -38.92	-1.64 – -1.23	**<0.001**	**<0.001**	2275.00
RoleSubstitution:DayMD-1	-29.57 ***	-0.94	-35.43 – -23.72	-1.12 – -0.75	**<0.001**	**<0.001**	2275.00
RoleStarter:DayMD-2	-51.56 ***	-1.63	-57.90 – -45.22	-1.83 – -1.43	**<0.001**	**<0.001**	2275.00
RoleSubstitution:DayMD-2	-30.41 ***	-0.96	-36.18 – -24.64	-1.15 – -0.78	**<0.001**	**<0.001**	2275.00
RoleStarter:DayMD-3	-53.95 ***	-1.71	-62.59 – -45.31	-1.98 – -1.43	**<0.001**	**<0.001**	2275.00
RoleSubstitution:DayMD-3	-34.08 ***	-1.08	-41.57 – -26.59	-1.32 – -0.84	**<0.001**	**<0.001**	2275.00
Random Effects							
σ^2	393.31						
$\tau_{00\ num.day}$	135.89						
$\tau_{00\ PlayerID}$	7.86						
$\tau_{11\ num.day.RoleStarter}$	210.71						
$\tau_{11\ num.day.RoleSubstitution}$	12.00						
$\rho_{01\ num.day.RoleStarter}$	0.46						
$\rho_{01\ num.day.RoleSubstitution}$	0.99						
$N_{num.day}$	71						
$N_{PlayerID}$	47						
Observations	2299						
Marginal R^2 / Conditional R^2	0.378 / NA						

** p<0.05   ** p<0.01   *** p<0.001*

Figure 4: Visualization of Random Slope Model for Total Duration



MSOC: Men's Program; WSOC: Women's Program; MD: Match Day; MD-3: Match Day minus 3; MD-2: Match Day minus 2; MD-1: Match Day minus 1

Table 6: Mixed Effect Model Results for Total Player Load

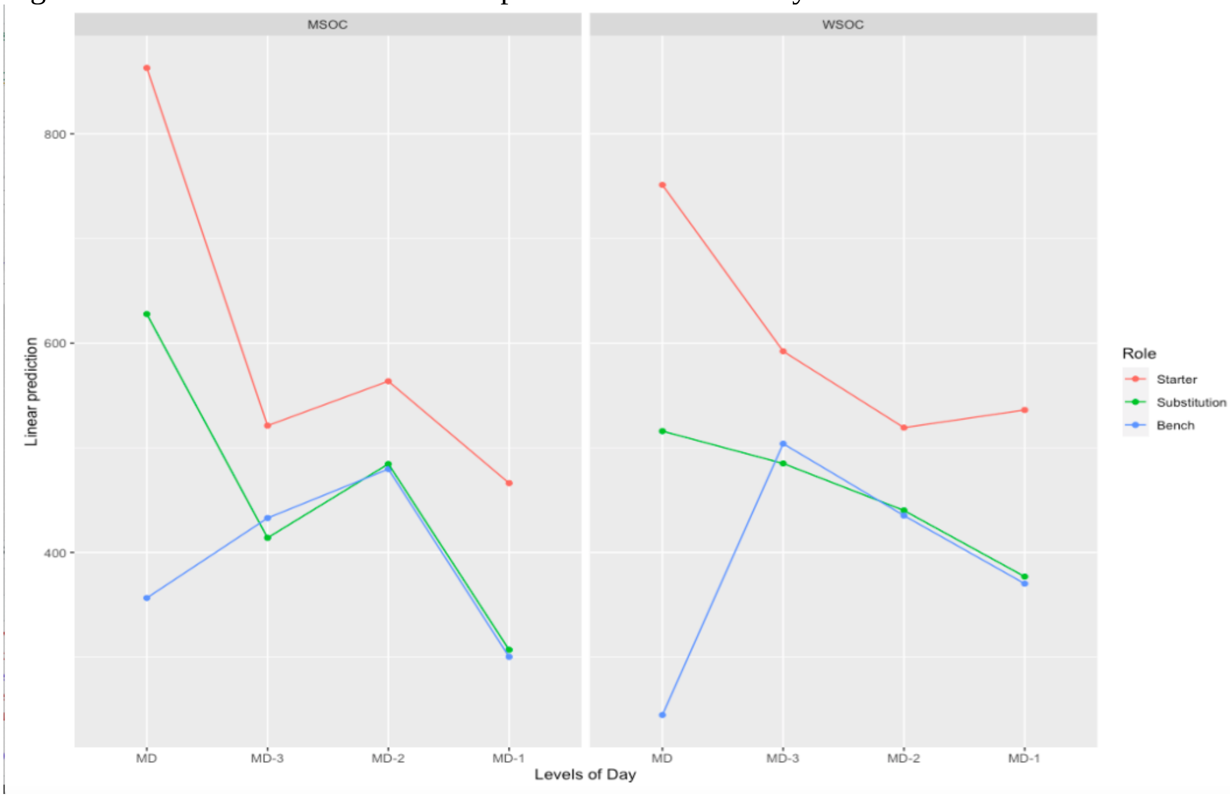
	Total Player Load					
Predictors	*Estimates*	*std. Beta*	*CI*	*standardized CI*	*p*	*df*
(Intercept)	521.06 ***	0.06	435.49 – 606.64	-0.20 – 0.32	**<0.001**	2275.00
Program [WSOC]	71.07 *	0.22	1.15 – 140.99	0.00 – 0.43	**0.046**	2275.00
Role [Substitution]	-107.19 *	-0.33	-203.90 – -10.48	-0.63 – -0.03	**0.030**	2275.00
Role [Bench]	-88.29	-0.27	-188.52 – 11.94	-0.58 – 0.04	0.084	2275.00
DayMD-2	42.49	0.13	-26.73 – 111.72	-0.08 – 0.34	0.229	2275.00
DayMD-1	-54.93	-0.17	-126.59 – 16.73	-0.39 – 0.05	0.133	2275.00
Day [MD]	341.85 ***	1.05	269.78 – 413.92	0.83 – 1.27	**<0.001**	2275.00
ProgramWSOC:DayMD-2	-115.47 **	-0.36	-187.65 – -43.29	-0.58 – -0.13	**0.002**	2275.00
ProgramWSOC:DayMD-1	-1.15	-0.00	-74.62 – 72.33	-0.23 – 0.22	0.976	2275.00
Program [WSOC] × Day [MD]	-182.88 ***	-0.56	-253.87 – -111.89	-0.78 – -0.34	**<0.001**	2275.00
RoleSubstitution:DayMD-2	28.10	0.09	-60.41 – 116.61	-0.19 – 0.36	0.534	2275.00
RoleBench:DayMD-2	4.31	0.01	-84.22 – 92.84	-0.26 – 0.29	0.924	2275.00
RoleSubstitution:DayMD-1	-52.03	-0.16	-142.06 – 38.00	-0.44 – 0.12	0.257	2275.00
RoleBench:DayMD-1	-77.66	-0.24	-168.68 – 13.36	-0.52 – 0.04	0.094	2275.00
Role [Substitution] × Day [MD]	-128.05 **	-0.39	-218.18 – -37.93	-0.67 – -0.12	**0.005**	2275.00
Role [Bench] × Day [MD]	-418.20 ***	-1.29	-508.55 – -327.84	-1.56 – -1.01	**<0.001**	2275.00

Table 6 (cont'd)

Random Effects	
σ^2	37388.29
$\tau_{00\ \text{num.day}}$	56353.09
$\tau_{00\ \text{PlayerID}}$	3222.85
$\tau_{11\ \text{num.day.RoleSubstitution}}$	41937.78
$\tau_{11\ \text{num.day.RoleBench}}$	51175.77
$\rho_{01\ \text{num.day.RoleSubstitution}}$	-0.94
$\rho_{01\ \text{num.day.RoleBench}}$	-0.97
$N_{\text{num.day}}$	71
N_{PlayerID}	47
Observations	2299
Marginal R^2 / Conditional R^2	0.386 / NA

* *p<0.05* ** *p<0.01* *** *p<0.001*

Figure 5: Visualization of Random Slope Model for Total Player Load



MSOC: Men's Program; WSOC: Women's Program; MD: Match Day; MD-3: Match Day minus 3; MD-2: Match Day minus 2; MD-1: Match Day minus 1

Table 7: Mixed Effect Model Results for Total Distance

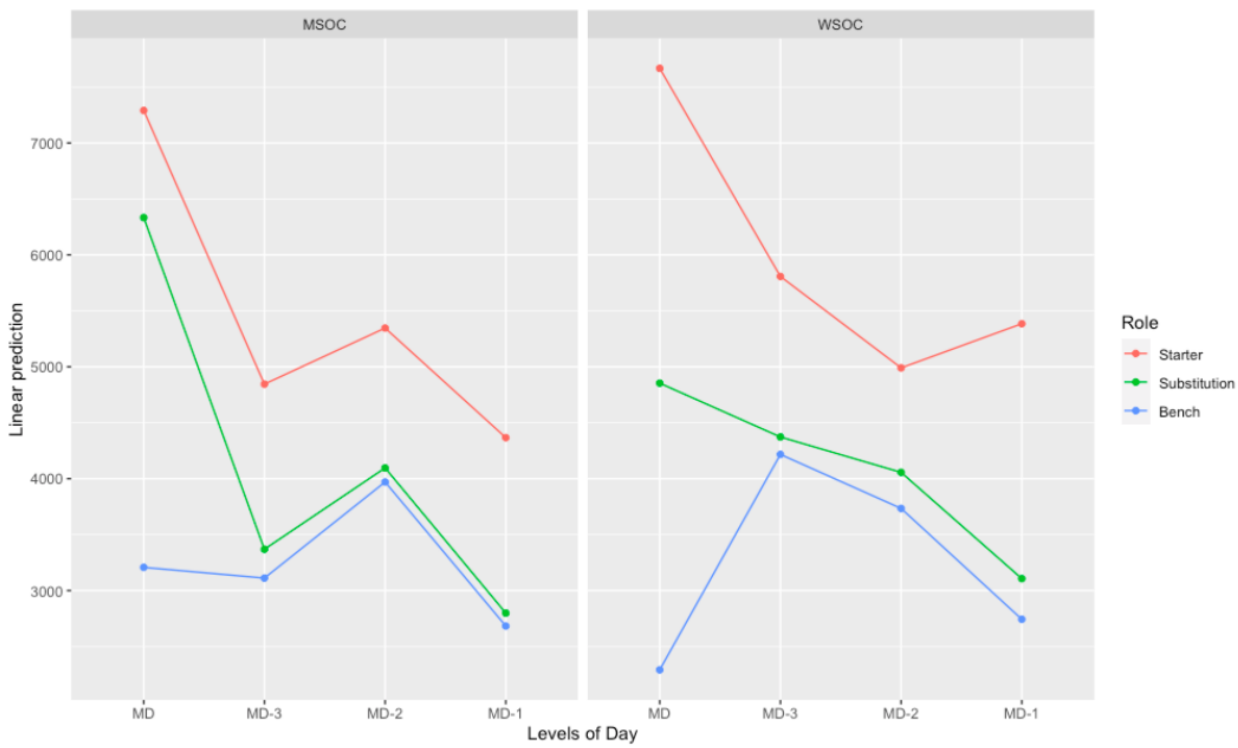
	Total Distance (mi)						
Predictors	*Estimates*	*std. Beta*	*CI*	*standardized CI*	*p*	*std. p*	*df*
(Intercept)	3207.26 ***	-0.45	2684.13 – 3730.39	-0.61 – -0.29	**<0.001**	**<0.001**	2174.00
Program [WSOC]	-915.92 *	-0.28	-1620.11 – -211.74	-0.50 – -0.07	**0.011**	**0.011**	2174.00
Role [Starter]	4083.58 ***	1.26	3136.36 – 5030.80	0.97 – 1.55	**<0.001**	**<0.001**	2174.00
Role [Substitution]	3125.99 ***	0.97	2482.65 – 3769.34	0.77 – 1.16	**<0.001**	**<0.001**	2174.00
DayMD-1	-524.47	-0.16	-1194.09 – 145.15	-0.37 – 0.04	0.125	0.125	2174.00
DayMD-2	763.09 *	0.24	116.20 – 1409.99	0.04 – 0.44	**0.021**	**0.021**	2174.00
DayMD-3	-96.04	-0.03	-852.02 – 659.94	-0.26 – 0.20	0.803	0.804	2174.00
Program [WSOC] × Role [Starter]	1292.59 **	0.40	361.50 – 2223.68	0.11 – 0.69	**0.007**	**0.007**	2174.00
Program [WSOC] × Role [Substitution]	-563.78	-0.17	-1479.27 – 351.72	-0.46 – 0.11	0.227	0.227	2174.00
ProgramWSOC:DayMD-1	976.11 *	0.30	71.70 – 1880.51	0.02 – 0.58	**0.034**	**0.034**	2174.00
ProgramWSOC:DayMD-2	679.48	0.21	-188.57 – 1547.54	-0.06 – 0.48	0.125	0.125	2174.00
ProgramWSOC:DayMD-3	2021.25 **	0.62	817.29 – 3225.21	0.25 – 1.00	**0.001**	**0.001**	2174.00
RoleStarter:DayMD-1	-2399.85 ***	-0.74	-3329.83 – -1469.87	-1.03 – -0.45	**<0.001**	**<0.001**	2174.00
RoleSubstitution:DayMD-1	-3010.17 ***	-0.93	-3809.08 – -2211.27	-1.18 – -0.68	**<0.001**	**<0.001**	2174.00
RoleStarter:DayMD-2	-2707.80 ***	-0.84	-3620.08 – -1795.52	-1.12 – -0.55	**<0.001**	**<0.001**	2174.00
RoleSubstitution:DayMD-2	-3000.50 ***	-0.93	-3785.73 – -2215.26	-1.17 – -0.68	**<0.001**	**<0.001**	2174.00
RoleStarter:DayMD-3	-2350.18 ***	-0.73	-3456.34 – -1244.03	-1.07 – -0.38	**<0.001**	**<0.001**	2174.00
RoleSubstitution:DayMD-3	-2868.38 ***	-0.89	-3797.20 – -1939.56	-1.17 – -0.60	**<0.001**	**<0.001**	2174.00
ProgramWSOC:RoleStarter:DayMD-1	-334.38	-0.10	-1543.71 – 874.94	-0.48 – 0.27	0.588	0.588	2174.00
ProgramWSOC:RoleSubstitution:DayMD-1	811.35	0.25	-319.89 – 1942.59	-0.10 – 0.60	0.160	0.160	2174.00
ProgramWSOC:RoleStarter:DayMD-2	-1412.19 *	-0.44	-2609.68 – -214.71	-0.81 – -0.07	**0.021**	**0.021**	2174.00
ProgramWSOC:RoleSubstitution:DayMD-2	760.62	0.23	-345.05 – 1866.28	-0.11 – 0.58	0.177	0.177	2174.00
ProgramWSOC:RoleStarter:DayMD-3	-1435.20	-0.44	-3130.42 – 260.01	-0.97 – 0.08	0.097	0.097	2174.00
ProgramWSOC:RoleSubstitution:DayMD-3	462.17	0.14	-1091.67 – 2016.02	-0.34 – 0.62	0.560	0.560	2174.00

Table 7 (cont'd)

Random Effects	
σ^2	3602859.17
$\tau_{00\ num.day}$	246127.99
$\tau_{00\ PlayerID}$	113949.22
$\tau_{11\ num.day.RoleStarter}$	7378999.29
$\tau_{11\ num.day.RoleSubstitution}$	88819.18
$\rho_{01\ num.day.RoleStarter}$	-0.32
$\rho_{01\ num.day.RoleSubstitution}$	0.44
ICC	0.48
$N_{num.day}$	70
$N_{PlayerID}$	47
Observations	2206
Marginal R^2 / Conditional R^2	0.268 / 0.621

* *p<0.05* ** *p<0.01* *** *p<0.001*

Figure 6: Visualization of Random Slope Model for Total Distance



MSOC: Men's Program; WSOC: Women's Program; MD: Match Day; MD-3: Match Day minus 3; MD-2: Match Day minus 2; MD-1: Match Day minus 1

Table 8: Mixed Effect Model Results for HSR Distance

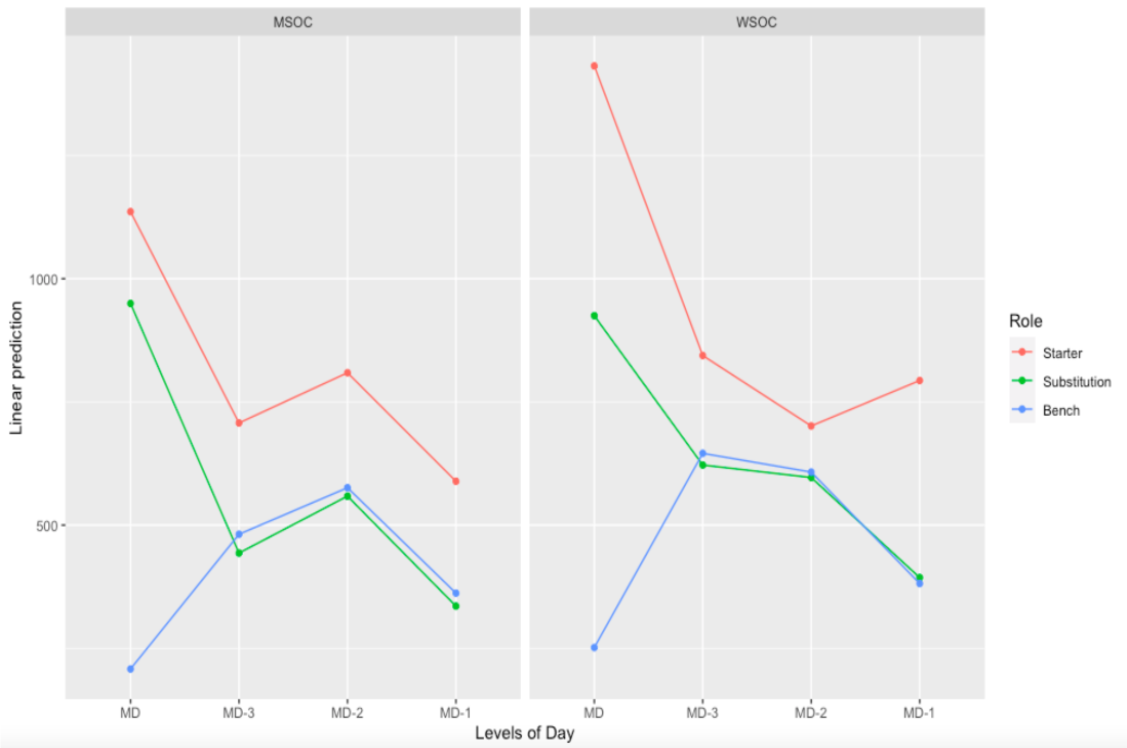
	HSR					
Predictors	*Estimates*	*std. Beta*	*CI*	*standardized CI*	*p*	*df*
(Intercept)	208.08 **	-0.73	71.09 – 345.07	-0.94 – -0.53	**0.003**	2174.00
Program [WSOC]	43.54	0.06	-142.61 – 229.70	-0.21 – 0.34	0.646	2174.00
Role [Starter]	927.93 ***	1.37	719.94 – 1135.92	1.06 – 1.68	**<0.001**	2174.00
Role [Substitution]	741.70 ***	1.09	571.36 – 912.05	0.84 – 1.35	**<0.001**	2174.00
DayMD-1	153.89 *	0.23	8.46 – 299.32	0.01 – 0.44	**0.038**	2174.00
DayMD-2	367.78 ***	0.54	227.32 – 508.24	0.34 – 0.75	**<0.001**	2174.00
DayMD-3	273.40 **	0.40	109.07 – 437.73	0.16 – 0.65	**0.001**	2174.00
Program [WSOC] × Role [Starter]	252.26 *	0.37	12.76 – 491.75	0.02 – 0.73	**0.039**	2174.00
Program [WSOC] × Role [Substitution]	-68.46	-0.10	-313.91 – 177.00	-0.46 – 0.26	0.584	2174.00
ProgramWSOC:DayMD-1	-24.11	-0.04	-219.69 – 171.47	-0.32 – 0.25	0.809	2174.00
ProgramWSOC:DayMD-2	-11.80	-0.02	-199.34 – 175.74	-0.29 – 0.26	0.902	2174.00
ProgramWSOC:DayMD-3	120.67	0.18	-139.76 – 381.11	-0.21 – 0.56	0.364	2174.00
RoleStarter:DayMD-1	-700.95 ***	-1.03	-896.67 – -505.22	-1.32 – -0.75	**<0.001**	2174.00
RoleSubstitution:DayMD-1	-768.01 ***	-1.13	-939.00 – -597.02	-1.39 – -0.88	**<0.001**	2174.00
RoleStarter:DayMD-2	-694.58 ***	-1.03	-886.52 – -502.65	-1.31 – -0.74	**<0.001**	2174.00
RoleSubstitution:DayMD-2	-758.78 ***	-1.12	-926.80 – -590.75	-1.37 – -0.87	**<0.001**	2174.00
RoleStarter:DayMD-3	-702.14 ***	-1.04	-934.46 – -469.82	-1.38 – -0.69	**<0.001**	2174.00
RoleSubstitution:DayMD-3	-779.83 ***	-1.15	-978.77 – -580.90	-1.44 – -0.86	**<0.001**	2174.00
ProgramWSOC:RoleStarter:DayMD-1	-67.18	-0.10	-322.74 – 188.37	-0.48 – 0.28	0.606	2174.00
ProgramWSOC:RoleSubstitution:DayMD-1	106.82	0.16	-135.38 – 349.01	-0.20 – 0.52	0.387	2174.00
ProgramWSOC:RoleStarter:DayMD-2	-392.02 **	-0.58	-644.74 – -139.29	-0.95 – -0.21	**0.002**	2174.00
ProgramWSOC:RoleSubstitution:DayMD-2	74.47	0.11	-162.20 – 311.14	-0.24 – 0.46	0.537	2174.00
ProgramWSOC:RoleStarter:DayMD-3	-279.63	-0.41	-635.53 – 76.27	-0.94 – 0.11	0.124	2174.00
ProgramWSOC:RoleSubstitution:DayMD-3	82.79	0.12	-249.88 – 415.46	-0.37 – 0.61	0.626	2174.00

Table 8 (cont'd)

Random Effects	
σ^2	165363.86
τ_{00} num.day	14465.40
τ_{00} PlayerID	14298.94
τ_{11} num.day.RoleStarter	211807.21
τ_{11} num.day.RoleSubstitution	1609.98
ρ_{01} num.day.RoleStarter	0.05
ρ_{01} num.day.RoleSubstitution	1.00
N num.day	70
N PlayerID	47
Observations	2206
Marginal R^2 / Conditional R^2	0.402 / NA

* $p<0.05$ ** $p<0.01$ *** $p<0.001$

Figure 7: Visualization of Random Slope Model for HSR Distance



MSOC: Men's Program; WSOC: Women's Program; MD: Match Day; MD-3: Match Day minus 3; MD-2: Match Day minus 2; MD-1: Match Day minus 1

Table 9: Mixed Effect Model Results for Sprint Distance

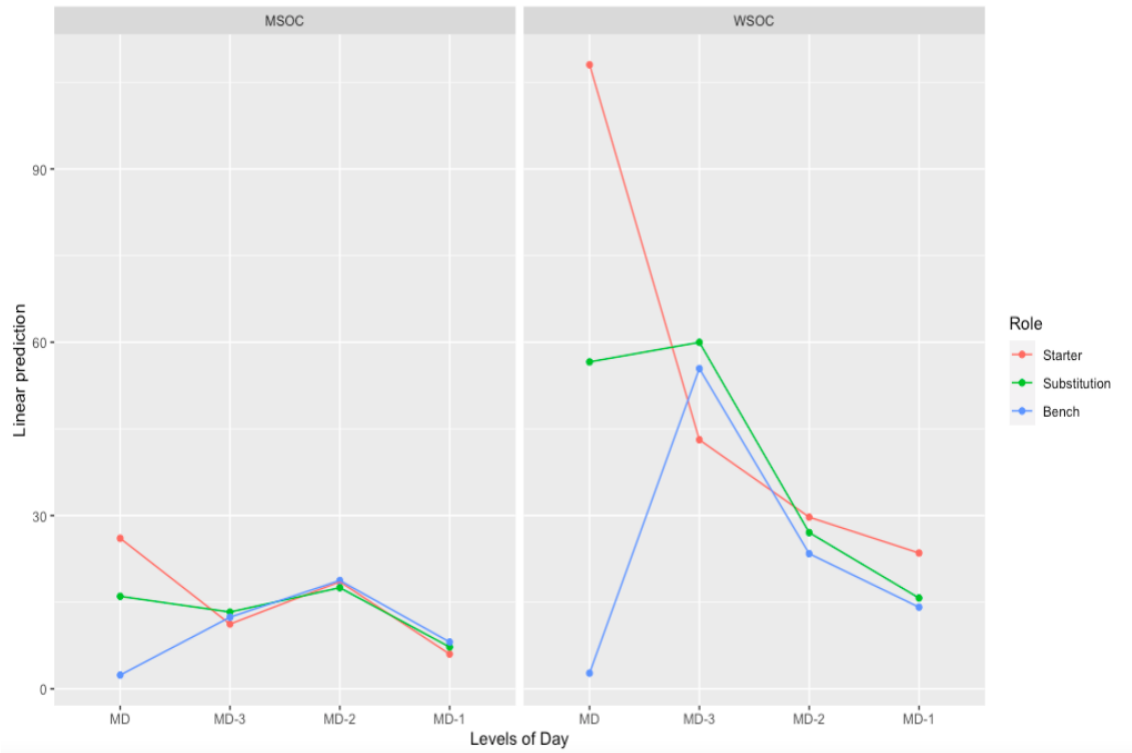
	SPR					
Predictors	*Estimates*	*std. Beta*	*CI*	*standardized CI*	*p*	*df*
(Intercept)	7.45	-0.41	-8.09 – 22.99	-0.71 – -0.11	0.347	2174.00
Program [WSOC]	-2.83	-0.05	-24.74 – 19.09	-0.47 – 0.37	0.800	2174.00
Role [Starter]	18.70	0.36	-2.01 – 39.42	-0.04 – 0.76	0.077	2174.00
Role [Substitution]	8.98	0.17	-12.08 – 30.04	-0.23 – 0.58	0.403	2174.00
DayMD-1	0.84	0.02	-10.37 – 12.04	-0.20 – 0.23	0.884	2174.00
DayMD-2	8.74	0.17	-2.09 – 19.58	-0.04 – 0.38	0.114	2174.00
DayMD-3	4.40	0.08	-8.27 – 17.07	-0.16 – 0.33	0.496	2174.00
Program [WSOC] × Role [Starter]	84.87 ***	1.63	56.98 – 112.77	1.09 – 2.16	**<0.001**	2174.00
Program [WSOC] × Role [Substitution]	42.35 **	0.81	12.10 – 72.61	0.23 – 1.39	**0.006**	2174.00
ProgramWSOC:DayMD-1	6.41	0.12	-9.15 – 21.96	-0.18 – 0.42	0.419	2174.00
ProgramWSOC:DayMD-2	9.46	0.18	-5.55 – 24.47	-0.11 – 0.47	0.217	2174.00
ProgramWSOC:DayMD-3	41.32 ***	0.79	20.53 – 62.12	0.39 – 1.19	**<0.001**	2174.00
RoleStarter:DayMD-1	-20.97 **	-0.40	-36.43 – -5.50	-0.70 – -0.11	**0.008**	2174.00
RoleSubstitution:DayMD-1	-10.27	-0.20	-26.32 – 5.78	-0.50 – 0.11	0.210	2174.00
RoleStarter:DayMD-2	-16.49 *	-0.32	-31.67 – -1.30	-0.61 – -0.02	**0.033**	2174.00
RoleSubstitution:DayMD-2	-8.22	-0.16	-23.96 – 7.52	-0.46 – 0.14	0.306	2174.00
RoleStarter:DayMD-3	-19.21 *	-0.37	-37.49 – -0.94	-0.72 – -0.02	**0.039**	2174.00
RoleSubstitution:DayMD-3	-6.68	-0.13	-25.30 – 11.95	-0.49 – 0.23	0.482	2174.00
ProgramWSOC:RoleStarter:DayMD-1	-70.95 ***	-1.36	-91.58 – -50.33	-1.76 – -0.96	**<0.001**	2174.00
ProgramWSOC:RoleSubstitution:DayMD-1	-36.70 **	-0.70	-58.99 – -14.41	-1.13 – -0.28	**0.001**	2174.00
ProgramWSOC:RoleStarter:DayMD-2	-80.30 ***	-1.54	-100.72 – -59.88	-1.93 – -1.15	**<0.001**	2174.00
ProgramWSOC:RoleSubstitution:DayMD-2	-38.31 ***	-0.73	-60.02 – -16.59	-1.15 – -0.32	**0.001**	2174.00
ProgramWSOC:RoleStarter:DayMD-3	-92.55 ***	-1.77	-120.82 – -64.27	-2.32 – -1.23	**<0.001**	2174.00
ProgramWSOC:RoleSubstitution:DayMD-3	-37.68 *	-0.72	-68.09 – -7.28	-1.31 – -0.14	**0.015**	2174.00

Table 9 (cont'd)

Random Effects	
σ^2	1258.32
τ_{00} num.day	0.00
τ_{00} PlayerID	291.63
τ_{11} num.day.RoleStarter	259.24
τ_{11} num.day.RoleSubstitution	113.48
ρ_{01} num.day.RoleStarter	
ρ_{01} num.day.RoleSubstitution	
N num.day	70
N PlayerID	47
Observations	2206
Marginal R^2 / Conditional R^2	0.396 / NA

* *p<0.05* ** *p<0.01* *** *p<0.001*

Figure 8: Visualization of Random Slope Model for SPR Distance



MSOC: Men's Program; WSOC: Women's Program; MD: Match Day; MD-3: Match Day minus 3; MD-2: Match Day minus 2; MD-1: Match Day minus 1

Table 10: Mixed Effect Model Results for Medium Intensity ACC

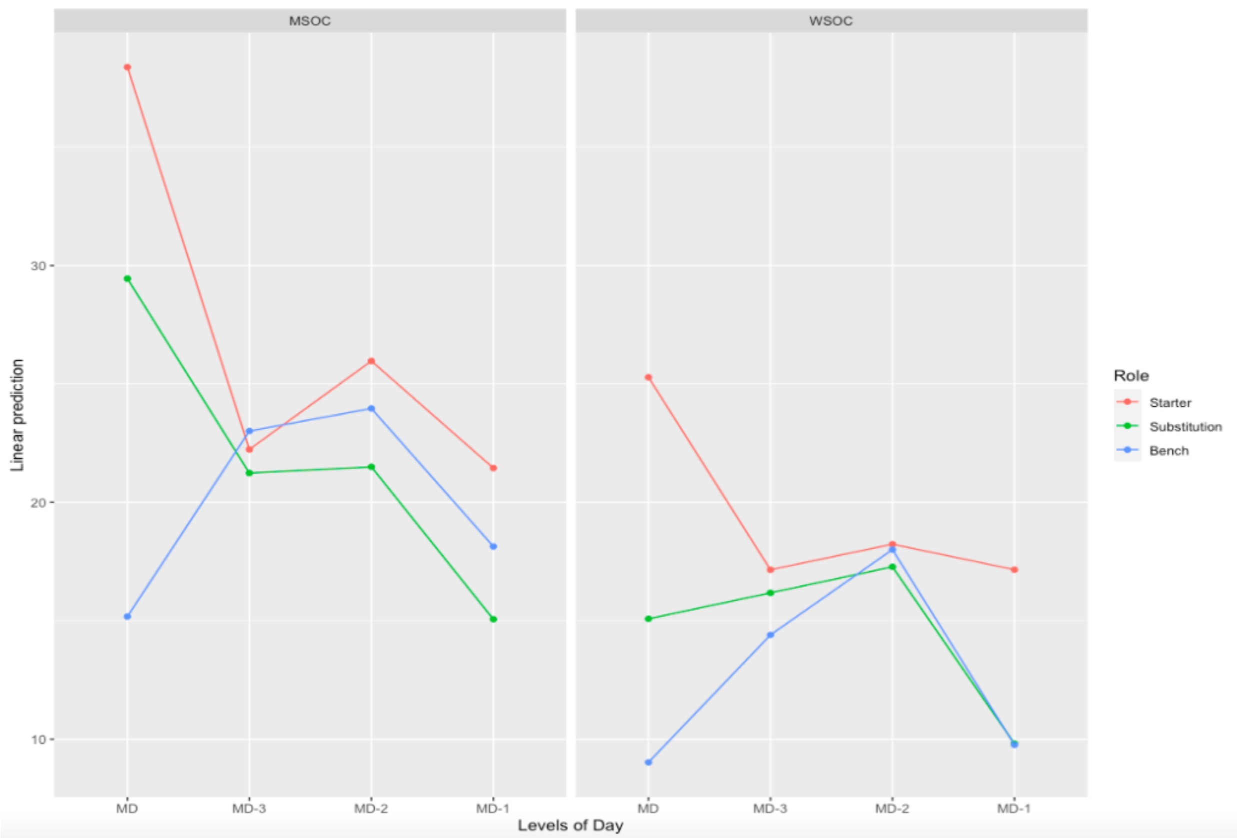
	MI ACC Efforts					
Predictors	*Estimates*	*std. Beta*	*CI*	*standardized CI*	*p*	*df*
(Intercept)	15.18 ***	-0.33	11.37 – 18.99	-0.59 – -0.08	**<0.001**	2174.00
Program [WSOC]	-6.16 *	-0.42	-11.21 – -1.10	-0.76 – -0.07	**0.017**	2174.00
Role [Starter]	23.20 ***	1.56	18.04 – 28.35	1.22 – 1.91	**<0.001**	2174.00
Role [Substitution]	14.27 ***	0.96	9.74 – 18.79	0.66 – 1.27	**<0.001**	2174.00
DayMD-1	2.96	0.20	-0.84 – 6.76	-0.06 – 0.46	0.127	2174.00
DayMD-2	8.78 ***	0.59	5.12 – 12.45	0.34 – 0.84	**<0.001**	2174.00
DayMD-3	7.83 ***	0.53	3.53 – 12.13	0.24 – 0.82	**<0.001**	2174.00
Program [WSOC] × Role [Starter]	-6.94 *	-0.47	-13.32 – -0.56	-0.90 – -0.04	**0.033**	2174.00
Program [WSOC] × Role [Substitution]	-8.21 *	-0.55	-14.76 – -1.66	-1.00 – -0.11	**0.014**	2174.00
ProgramWSOC:DayMD-1	-2.22	-0.15	-7.20 – 2.76	-0.49 – 0.19	0.382	2174.00
ProgramWSOC:DayMD-2	0.20	0.01	-4.55 – 4.95	-0.31 – 0.33	0.934	2174.00
ProgramWSOC:DayMD-3	-2.45	-0.17	-9.07 – 4.17	-0.61 – 0.28	0.468	2174.00
RoleStarter:DayMD-1	-19.89 ***	-1.34	-24.71 – -15.07	-1.67 – -1.02	**<0.001**	2174.00
RoleSubstitution:DayMD-1	-17.34 ***	-1.17	-21.36 – -13.33	-1.44 – -0.90	**<0.001**	2174.00
RoleStarter:DayMD-2	-21.19 ***	-1.43	-25.91 – -16.47	-1.75 – -1.11	**<0.001**	2174.00
RoleSubstitution:DayMD-2	-16.73 ***	-1.13	-20.68 – -12.78	-1.39 – -0.86	**<0.001**	2174.00
RoleStarter:DayMD-3	-23.97 ***	-1.62	-29.65 – -18.29	-2.00 – -1.23	**<0.001**	2174.00
RoleSubstitution:DayMD-3	-16.04 ***	-1.08	-20.70 – -11.39	-1.40 – -0.77	**<0.001**	2174.00
ProgramWSOC:RoleStarter:DayMD-1	11.02 ***	0.74	4.77 – 17.28	0.32 – 1.17	**0.001**	2174.00
ProgramWSOC:RoleSubstitution:DayMD-1	11.33 ***	0.76	5.63 – 17.03	0.38 – 1.15	**<0.001**	2174.00
ProgramWSOC:RoleStarter:DayMD-2	5.16	0.35	-0.98 – 11.31	-0.07 – 0.76	0.100	2174.00
ProgramWSOC:RoleSubstitution:DayMD-2	9.94 ***	0.67	4.38 – 15.51	0.30 – 1.05	**<0.001**	2174.00
ProgramWSOC:RoleStarter:DayMD-3	10.46 *	0.71	1.85 – 19.08	0.12 – 1.29	**0.017**	2174.00
ProgramWSOC:RoleSubstitution:DayMD-3	11.76 **	0.79	3.91 – 19.60	0.26 – 1.32	**0.003**	2174.00

Table 10 (cont'd)

Random Effects	
σ^2	91.51
τ_{00} num.day	19.15
τ_{00} PlayerID	11.84
τ_{11} num.day.RoleStarter	76.36
τ_{11} num.day.RoleSubstitution	1.09
ρ_{01} num.day.RoleStarter	-0.09
ρ_{01} num.day.RoleSubstitution	-0.38
N num.day	70
N PlayerID	47
Observations	2206
Marginal R^2 / Conditional R^2	0.351 / NA

* *p<0.05* ** *p<0.01* *** *p<0.001*

Figure 9: Visualization of Random Slope Model for Medium Intensity Acceleration Counts



MSOC: Men's Program; WSOC: Women's Program; MD: Match Day; MD-3: Match Day minus 3; MD-2: Match Day minus 2; MD-1: Match Day minus 1

Table 11: Mixed Effect Model Results for High Intensity ACC

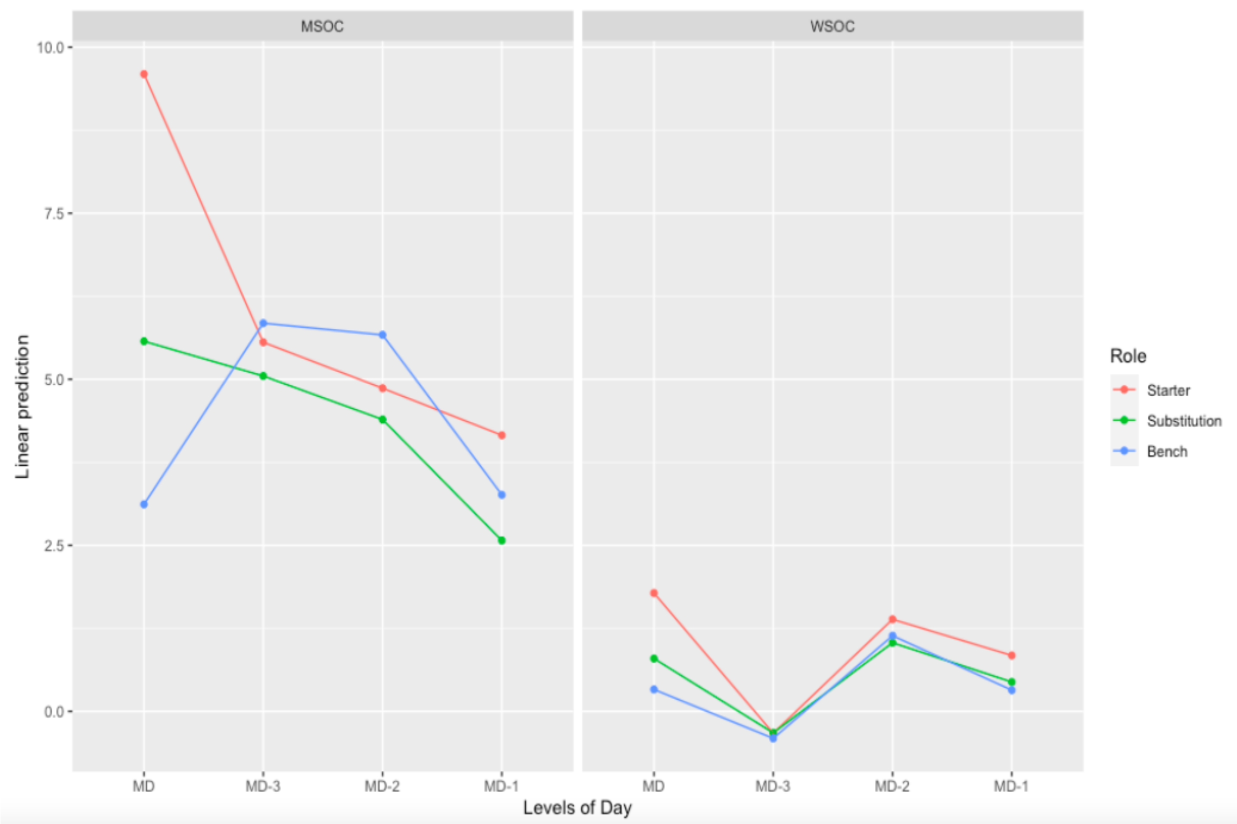
	HI ACC Efforts					
Predictors	*Estimates*	*std. Beta*	*CI*	*standardized CI*	*p*	*df*
(Intercept)	3.12 ***	0.04	1.96 – 4.27	-0.23 – 0.32	**<0.001**	2174.00
Program [WSOC]	-2.79 ***	-0.67	-4.36 – -1.21	-1.04 – -0.29	**0.001**	2174.00
Role [Starter]	6.48 ***	1.55	5.01 – 7.95	1.20 – 1.90	**<0.001**	2174.00
Role [Substitution]	2.46 ***	0.59	1.02 – 3.89	0.24 – 0.93	**0.001**	2174.00
DayMD-1	0.14	0.03	-0.86 – 1.14	-0.20 – 0.27	0.779	2174.00
DayMD-2	2.55 ***	0.61	1.58 – 3.52	0.38 – 0.84	**<0.001**	2174.00
DayMD-3	2.73 ***	0.65	1.60 – 3.86	0.38 – 0.92	**<0.001**	2174.00
Program [WSOC] × Role [Starter]	-5.03 ***	-1.20	-6.99 – -3.06	-1.67 – -0.73	**<0.001**	2174.00
Program [WSOC] × Role [Substitution]	-1.99	-0.48	-4.08 – 0.10	-0.98 – 0.02	0.062	2174.00
ProgramWSOC:DayMD-1	-0.15	-0.04	-1.48 – 1.18	-0.36 – 0.28	0.821	2174.00
ProgramWSOC:DayMD-2	-1.74 **	-0.42	-3.02 – -0.47	-0.72 – -0.11	**0.007**	2174.00
ProgramWSOC:DayMD-3	-3.46 ***	-0.83	-5.24 – -1.69	-1.25 – -0.40	**<0.001**	2174.00
RoleStarter:DayMD-1	-5.58 ***	-1.34	-6.81 – -4.36	-1.63 – -1.04	**<0.001**	2174.00
RoleSubstitution:DayMD-1	-3.14 ***	-0.75	-4.26 – -2.03	-1.02 – -0.49	**<0.001**	2174.00
RoleStarter:DayMD-2	-7.28 ***	-1.74	-8.49 – -6.08	-2.03 – -1.45	**<0.001**	2174.00
RoleSubstitution:DayMD-2	-3.73 ***	-0.89	-4.83 – -2.63	-1.16 – -0.63	**<0.001**	2174.00
RoleStarter:DayMD-3	-6.77 ***	-1.62	-8.21 – -5.33	-1.96 – -1.27	**<0.001**	2174.00
RoleSubstitution:DayMD-3	-3.25 ***	-0.78	-4.54 – -1.96	-1.09 – -0.47	**<0.001**	2174.00
ProgramWSOC:RoleStarter:DayMD-1	4.65 ***	1.11	3.03 – 6.27	0.72 – 1.50	**<0.001**	2174.00
ProgramWSOC:RoleSubstitution:DayMD-1	2.80 ***	0.67	1.22 – 4.39	0.29 – 1.05	**0.001**	2174.00
ProgramWSOC:RoleStarter:DayMD-2	6.08 ***	1.45	4.48 – 7.68	1.07 – 1.84	**<0.001**	2174.00
ProgramWSOC:RoleSubstitution:DayMD-2	3.16 ***	0.76	1.61 – 4.71	0.38 – 1.13	**<0.001**	2174.00
ProgramWSOC:RoleStarter:DayMD-3	5.39 ***	1.29	3.18 – 7.60	0.76 – 1.82	**<0.001**	2174.00
ProgramWSOC:RoleSubstitution:DayMD-3	2.87 **	0.69	0.69 – 5.05	0.16 – 1.21	**0.010**	2174.00

Table 11 (cont'd)

Random Effects	
σ^2	7.09
τ_{00} num.day	1.03
τ_{00} PlayerID	1.35
τ_{11} num.day.RoleStarter	1.70
τ_{11} num.day.RoleSubstitution	0.05
ρ_{01} num.day.RoleStarter	0.01
ρ_{01} num.day.RoleSubstitution	-0.96
N num.day	70
N PlayerID	47
Observations	2206
Marginal R^2 / Conditional R^2	0.483 / NA

* *p<0.05* ** *p<0.01* *** *p<0.001*

Figure 10: Visualization of Random Slope Model for High Intensity Acceleration Counts



MSOC: Men's Program; WSOC: Women's Program; MD: Match Day; MD-3: Match Day minus 3; MD-2: Match Day minus 2; MD-1: Match Day minus 1

Table 12: Mixed Effect Model Results for Medium Intensity DEC

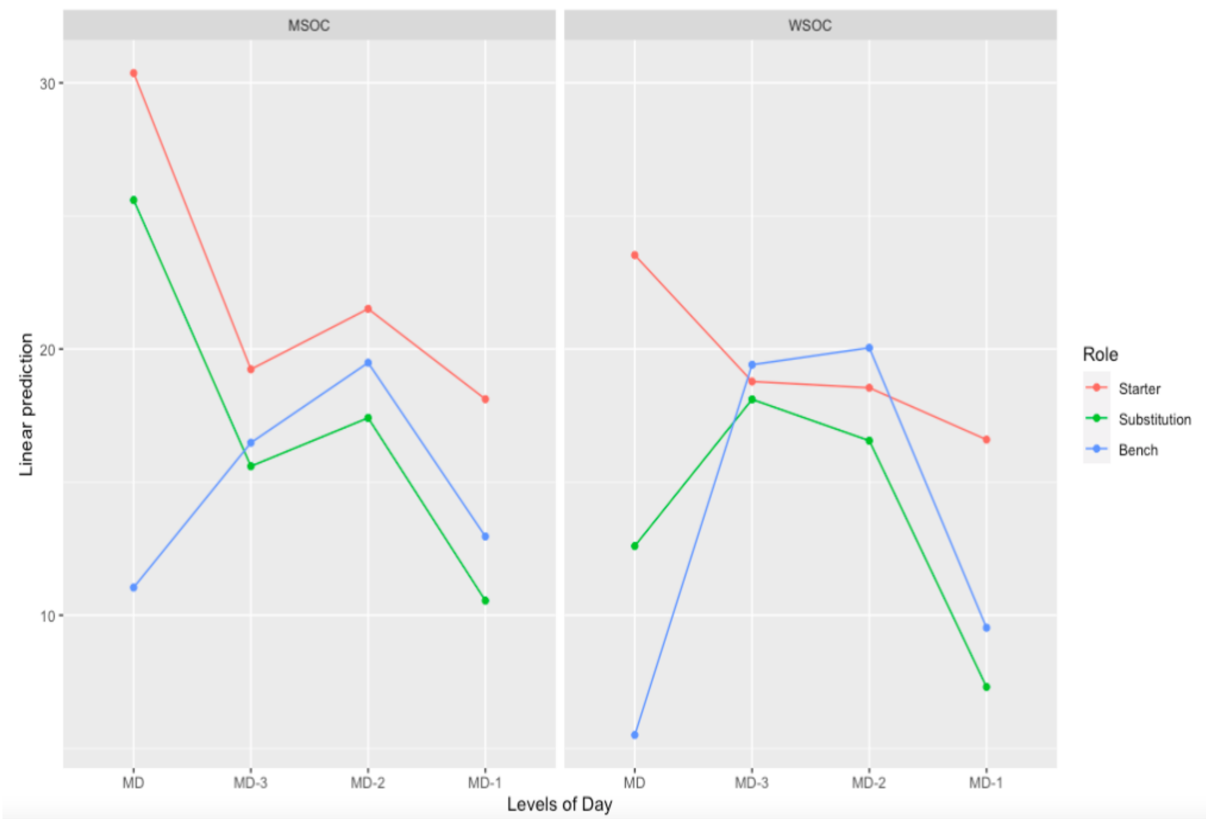
	MI DEC Efforts						
Predictors	*Estimates*	*std. Beta*	*CI*	*standardized CI*	*p*	*std. p*	*df*
(Intercept)	11.04 ***	-0.45	7.60 – 14.48	-0.69 – -0.20	**<0.001**	**<0.001**	2174.00
Program [WSOC]	-5.54 *	-0.39	-10.17 – -0.91	-0.72 – -0.06	**0.019**	**0.019**	2174.00
Role [Starter]	19.33 ***	1.37	14.38 – 24.28	1.02 – 1.73	**<0.001**	**<0.001**	2174.00
Role [Substitution]	14.56 ***	1.03	10.39 – 18.72	0.74 – 1.33	**<0.001**	**<0.001**	2174.00
DayMD-1	1.92	0.14	-1.58 – 5.41	-0.11 – 0.38	0.282	0.282	2174.00
DayMD-2	8.45 ***	0.60	5.07 – 11.82	0.36 – 0.84	**<0.001**	**<0.001**	2174.00
DayMD-3	5.44 **	0.39	1.49 – 9.39	0.11 – 0.67	**0.007**	**0.007**	2174.00
Program [WSOC] × Role [Starter]	-1.30	-0.09	-7.20 – 4.60	-0.51 – 0.33	0.665	0.665	2174.00
Program [WSOC] × Role [Substitution]	-7.46 *	-0.53	-13.49 – -1.43	-0.96 – -0.10	**0.015**	**0.015**	2174.00
ProgramWSOC:DayMD-1	2.11	0.15	-2.52 – 6.74	-0.18 – 0.48	0.371	0.371	2174.00
ProgramWSOC:DayMD-2	6.10 **	0.43	1.67 – 10.53	0.12 – 0.75	**0.007**	**0.007**	2174.00
ProgramWSOC:DayMD-3	8.47 **	0.60	2.32 – 14.63	0.16 – 1.04	**0.007**	**0.007**	2174.00
RoleStarter:DayMD-1	-14.17 ***	-1.01	-18.73 – -9.61	-1.33 – -0.68	**<0.001**	**<0.001**	2174.00
RoleSubstitution:DayMD-1	-16.97 ***	-1.21	-20.79 – -13.15	-1.48 – -0.93	**<0.001**	**<0.001**	2174.00
RoleStarter:DayMD-2	-17.30 ***	-1.23	-21.77 – -12.84	-1.55 – -0.91	**<0.001**	**<0.001**	2174.00
RoleSubstitution:DayMD-2	-16.63 ***	-1.18	-20.39 – -12.87	-1.45 – -0.92	**<0.001**	**<0.001**	2174.00
RoleStarter:DayMD-3	-16.57 ***	-1.18	-21.96 – -11.18	-1.56 – -0.80	**<0.001**	**<0.001**	2174.00
RoleSubstitution:DayMD-3	-15.44 ***	-1.10	-19.87 – -11.01	-1.41 – -0.78	**<0.001**	**<0.001**	2174.00
ProgramWSOC:RoleStarter:DayMD-1	3.21	0.23	-2.71 – 9.13	-0.19 – 0.65	0.288	0.288	2174.00
ProgramWSOC:RoleSubstitution:DayMD-1	7.64 **	0.54	2.22 – 13.07	0.16 – 0.93	**0.006**	**0.006**	2174.00
ProgramWSOC:RoleStarter:DayMD-2	-2.23	-0.16	-8.06 – 3.61	-0.57 – 0.26	0.454	0.454	2174.00
ProgramWSOC:RoleSubstitution:DayMD-2	6.04 *	0.43	0.74 – 11.35	0.05 – 0.81	**0.026**	**0.026**	2174.00
ProgramWSOC:RoleStarter:DayMD-3	-2.09	-0.15	-10.29 – 6.11	-0.73 – 0.43	0.618	0.618	2174.00
ProgramWSOC:RoleSubstitution:DayMD-3	7.04	0.50	-0.43 – 14.51	-0.03 – 1.03	0.065	0.065	2174.00

Table 12 (cont'd)

Random Effects	
σ^2	83.54
$\tau_{00\ num.day}$	11.94
$\tau_{00\ PlayerID}$	9.71
$\tau_{11\ num.day.RoleStarter}$	97.55
$\tau_{11\ num.day.RoleSubstitution}$	0.29
$\rho_{01\ num.day.RoleStarter}$	-0.07
$\rho_{01\ num.day.RoleSubstitution}$	-0.65
$N_{num.day}$	70
$N_{PlayerID}$	47
Observations	2206
Marginal R^2 / Conditional R^2	0.307 / NA

* *p<0.05* ** *p<0.01* *** *p<0.001*

Figure 11: Visualization of Random Slope Model for Medium Intensity Deceleration Counts



MSOC: Men's Program; WSOC: Women's Program; MD: Match Day; MD-3: Match Day minus 3; MD-2: Match Day minus 2; MD-1: Match Day minus 1

Table 13: Mixed Effect Model Results for High Intensity DEC

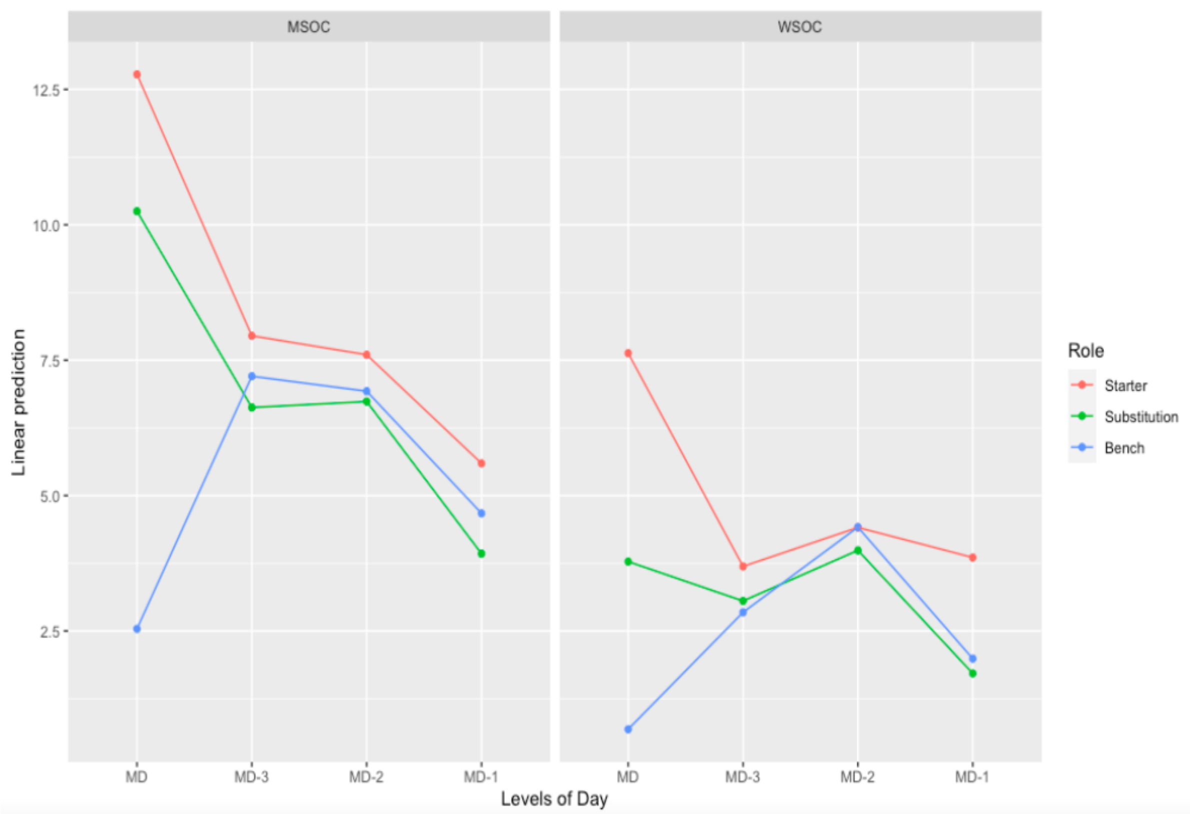
	HI DEC Efforts					
Predictors	*Estimates*	*std. Beta*	*CI*	*standardized CI*	*p*	*df*
(Intercept)	2.54 **	-0.47	0.99 – 4.09	-0.73 – -0.22	**0.001**	2174.00
Program [WSOC]	-1.85	-0.30	-3.98 – 0.28	-0.65 – 0.05	0.088	2174.00
Role [Starter]	10.24 ***	1.68	8.16 – 12.32	1.34 – 2.02	**<0.001**	2174.00
Role [Substitution]	7.71 ***	1.27	5.75 – 9.67	0.94 – 1.59	**<0.001**	2174.00
DayMD-1	2.13 **	0.35	0.70 – 3.57	0.11 – 0.59	**0.004**	2174.00
DayMD-2	4.39 ***	0.72	3.00 – 5.78	0.49 – 0.95	**<0.001**	2174.00
DayMD-3	4.67 ***	0.77	3.04 – 6.29	0.50 – 1.03	**<0.001**	2174.00
Program [WSOC] × Role [Starter]	-3.30 *	-0.54	-5.99 – -0.60	-0.98 – -0.10	**0.017**	2174.00
Program [WSOC] × Role [Substitution]	-4.62 **	-0.76	-7.46 – -1.78	-1.22 – -0.29	**0.001**	2174.00
ProgramWSOC:DayMD-1	-0.83	-0.14	-2.77 – 1.11	-0.45 – 0.18	0.402	2174.00
ProgramWSOC:DayMD-2	-0.66	-0.11	-2.52 – 1.21	-0.41 – 0.20	0.490	2174.00
ProgramWSOC:DayMD-3	-2.51	-0.41	-5.10 – 0.08	-0.84 – 0.01	0.058	2174.00
RoleStarter:DayMD-1	-9.32 ***	-1.53	-11.18 – -7.46	-1.83 – -1.22	**<0.001**	2174.00
RoleSubstitution:DayMD-1	-8.46 ***	-1.39	-10.16 – -6.75	-1.67 – -1.11	**<0.001**	2174.00
RoleStarter:DayMD-2	-9.57 ***	-1.57	-11.39 – -7.74	-1.87 – -1.27	**<0.001**	2174.00
RoleSubstitution:DayMD-2	-7.90 ***	-1.30	-9.58 – -6.23	-1.57 – -1.02	**<0.001**	2174.00
RoleStarter:DayMD-3	-9.49 ***	-1.56	-11.69 – -7.29	-1.92 – -1.20	**<0.001**	2174.00
RoleSubstitution:DayMD-3	-8.29 ***	-1.36	-10.27 – -6.31	-1.68 – -1.03	**<0.001**	2174.00
ProgramWSOC:RoleStarter:DayMD-1	4.24 ***	0.70	1.78 – 6.70	0.29 – 1.10	**0.001**	2174.00
ProgramWSOC:RoleSubstitution:DayMD-1	5.09 ***	0.83	2.67 – 7.51	0.44 – 1.23	**<0.001**	2174.00
ProgramWSOC:RoleStarter:DayMD-2	2.62 *	0.43	0.18 – 5.05	0.03 – 0.83	**0.035**	2174.00
ProgramWSOC:RoleSubstitution:DayMD-2	4.38 ***	0.72	2.01 – 6.75	0.33 – 1.11	**<0.001**	2174.00
ProgramWSOC:RoleStarter:DayMD-3	3.40 *	0.56	0.01 – 6.78	0.00 – 1.11	**0.049**	2174.00
ProgramWSOC:RoleSubstitution:DayMD-3	5.40 **	0.89	2.07 – 8.73	0.34 – 1.43	**0.001**	2174.00

Table 13 (cont'd)

Random Effects	
σ^2	16.64
τ_{00} num.day	1.59
τ_{00} PlayerID	2.28
τ_{11} num.day.RoleStarter	7.73
τ_{11} num.day.RoleSubstitution	0.06
ρ_{01} num.day.RoleStarter	0.36
ρ_{01} num.day.RoleSubstitution	0.51
N num.day	70
N PlayerID	47
Observations	2206
Marginal R^2 / Conditional R^2	0.346 / NA

* *p<0.05* ** *p<0.01* *** *p<0.001*

Figure 12: Visualization of Random Slope Model for High Intensity Deceleration Counts



MSOC: Men's Program; WSOC: Women's Program; MD: Match Day; MD-3: Match Day minus 3; MD-2: Match Day minus 2; MD-1: Match Day minus 1

DISCUSSION

The purpose of this study was to examine the distribution of training loads throughout the NCAA soccer season, paying special attention to the effects of program, role, and day of microcycle on the observed training loads. Unsurprisingly, training loads were greatest on match day and lower on training days. Considering that the scheduling of the soccer season is similar for men's and women's NCAA soccer, the distribution of training loads was anticipated to be similar between the men's and women's soccer programs. Generally, this hypothesis was supported between the two programs under investigation. The effect of player role, starter, substitution, and bench, was expected to demonstrate greatest training loads amongst starters compared to other role groups. Again, this was supported amongst the roles in the observed programs. Altogether, this study identifies opportunities to better support the development and physical preparation of players throughout men's and women's NCAA soccer programs.

The structure of the NCAA microcycle is unique to college soccer. Professional soccer typically involves a 7-day microcycle with 6-days of training between matches during which training loads are reported to be lower on training days closer to match day[15,18,27]. The NCAA typically provides for 3-days of training between matches. Training loads at this level have been reported in men's soccer and are lowest on MD-1 while MD-2 and MD-3 training loads are similar[42]. This is the first study we are aware of evaluating training load distribution throughout the microcycle in women's soccer in the NCAA. Both the men's and women's programs under investigation demonstrated similar patterns for training load distribution with highest training loads on MD and lowest on MD-1. Training loads, amongst training days, were typically highest on MD-2 which were significantly greater than MD-1 while similar to MD-3. MD-3 training loads were not significantly different from MD-1 training loads. This pattern is different than what is observed in professional soccer where MD-3 training loads are reported to be greater than MD-2 and MD-1 training loads[15,18,27]. A major reason for this difference could reflect the proximity to the previous match. Within a 7-day microcycle, MD-3 is four days after the previous match whereas within a 4-day microcycle, MD-3 is one day after the previous match. Anecdotally, amongst the two programs, coaching staffs typically tried to plan for lighter practices on MD-3 to allow players to recover from the previous match whereas MD-3 and MD-4 present the highest training loads during the microcycle in professional soccer[18,27,33]. These shorter microcycles, therefore, provide little opportunity to prescribe for heavier training load training sessions during the regular season.

This study included the comparison of training loads between a men's and women's soccer program. Both men's and women's soccer compete during the Fall and have the same regular season and post-season schedule length. There are no rule differences (i.e., substitution allotment, duration of match, size of pitch) that would contribute to training load differences within matches. Despite the similarities, comparisons of men's and women's collegiate players are rarely made. At the professional level, Bradley and colleagues (2014) compared men's and women's players, identifying that men's players cover greater total distances and high speed running distances than women's players[39]. Bradley and colleague's study, however, compared men's and women's players using the same absolute velocity thresholds. This study applied separate high speed running and sprint thresholds that have been recommended to be specific to men and women[51] while maintaining similar acceleration thresholds for men and women. As a result, the women's program covered greater sprint distances than the men yet recorded less medium- and high-intensity accelerations and decelerations. This observation presents a number of questions. Predominantly, it is unclear whether women are actually performing less high-intensity accelerations and decelerations or if the thresholds used to characterize medium- and high-intensity acceleration and deceleration events for women's soccer need to be adjusted similar to velocity thresholds[51] This study highlights the need for additional study in this area to improve the applications of sports science to women's soccer.

Despite the differences in sprint, acceleration, and deceleration volumes within the men's and women's programs, each program's training loads were relatively similar to other respective programs at the NCAA level. Curtis and colleagues (2020) found men's players at one NCAA Division I program to accumulate 939 ± 198 AU of PlayerLoad, cover total distances of 9,367 ± 2,149 m, 1,417 ± 432 m of running (14.4-21.59 km•h^{-1}), and 283 ± 122 m of sprinting (>21.6 km•h^{-1}) when players participated in the entire 90-min match[46]. This compared to 790 ± 503 AU PlayerLoad, 7200 ± 4730 m distance, 1080 ± 981 m running distance, and 25.9 ± 29.2 m sprint distance observed within this program. On the women's side, players who completed entire 90-min matches covered 9486 ± 300 m of total distance, 1014 ± 118 m of high-speed running (>15 km•h^{-1}), and 428 ± 70 m of sprinting (>18 km•h^{-1})[47]. By comparison, the women in the observed program accumulated 646 ± 377 AU PlayerLoad, 6370 ± 3850 m distance, 1180 ± 842 m running distance, and 78.0 ± 90.5 m sprint distance. These similarities lend support to what demands may be expected, generally, across NCAA soccer programs.

Unlike previous studies examining training load distribution throughout the college soccer microcycle, this is the first, to our knowledge, to characterize players into starters, substitutes, and bench. Previous college soccer studies characterize players as starters and reserves similar to professional soccer. In professional soccer, starters will remain in the match until substitution or match completion as they are disallowed from renentering the match after substituting out of the match[27]. The remainder of the roster is categorized as reserve players and are available to substitute into the match so long as a team has not used all five of its substitutes[26]. NCAA soccer allows players to re-enter matches similar to rules seen in basketball, albeit not at the same rate, and does not limit the number of substitutes allotted to a team[43]. As result, some programs may see three groupings of players when evaluating the distribution of playing time across the team similar to that of basketball[165]. Supporting our hypothesis, our results demonstrated significant differences amongst the three role groups for most training load measures with highest training loads observed in starters while lowest observed in bench players. This differed from Curtis and colleagues (2020) findings that starters and reserves training loads were similar[42]. Contrasts, within this study, further revealed significant differences between the substitutes and bench players for most training load measures. However, these differences were only evident on match days, whereas training loads on practice days were similar between substitutes and bench players. Further investigation of other programs using similar methods may contribute a better understanding how other factors such as program success, coach philosophy, or roster size influence training loads.

The significance of these findings contributes to how these roles are currently trained within the NCAA microcycle while highlighting the potential undertraining amongst substitution and bench players. Anderson and colleagues (2016) recommended incorporating greater high-intensity training load during practices for reserve players who did not experience the high-intensity demands of competition in order to maintain fitness, game readiness, and reduce injury risk[33]. The same recommendations could be made for the two programs under investigation, but there are some caveats. While professional soccer is afforded opportunity post-match and on the MD+1 training session which is typically more than five days out from the next match, MD+1 for NCAA soccer often falls on MD-3. This means that training substitution and bench players intensely and achieving match volumes on MD+1 could have detrimental effects to player speed, power, strength, and perceived muscle soreness for the following 72-hours or on the subsequent MD[31]. Coaches and sports scientists prescribing training loads and practices during these sessions should consider increasing training loads on MD+1 for substitution and bench players to manage fitness and injury, but these loads should not reflect starter MD training loads as these training loads could reduce performance on the upcoming match.

Sports scientists may want to consider what volume and intensity of training can be prescribed on MD+1 to enhance fitness without detrimenting match performance at the NCAA level. One systematic review of recovery measures in soccer suggests recovery from a match requires 72-hours or more[171]. A number of measures may be used to determine recovery status in soccer. For instance, Andersson and colleagues (2008) used countermovement jump height, 20-m sprint time, eccentric knee extension strength, and perceived muscle soreness to assess recovery status post-match in professional women's players[31]. Female players at this level demonstrated sprint times returned to pre-match baselines within hours post-match while vertical jump height did not return to baseline at any point during the 3-days post-match. Isokinetic knee extension and flexion strength tests did not recover until 2- and 3-days post-match, respectively[31]. The perceived muscle soreness reported by these players returned to baseline 3-days post-match[31]. Additional study of player recovery status throughout the collegiate soccer microcycle using these markers of recovery could identify what percentage of match training load could be prescribed to substitutes and bench players to maintain or enhance fitness while limiting the fatigue experienced by players.

Stevens and colleagues (2017) highlight the value of presenting training loads as a percentage of match load for communication across a club[27]. Figures 3 and 4 provide training loads for each variable relative to anticipated starters match load. This value was determined as the average training load of all starters for each training load parameter. An alternative method of determining expected training loads could involve determining the total load accumulated by one position reflective of all players who played that position. This would, in theory, present the total match training load expected for an outside back over 90-minutes but may not reflect the anticipated demands of a single player during a match. By presenting training load relative to starters, we can prescribe training loads throughout the microcycle with the intent of preparing for starters' match day training load.

There are several limitations within this study including the study of a single men's and women's Division I soccer team across a single NCAA soccer season. The findings from this study may not be applicable to other programs throughout the NCAA provided differences in coaching preferences and philosophies on player substitution, usage, and development, team tactics and formation, environmental differences, and level of play[153]. Additional investigation of role differences throughout NCAA soccer paying special attention to roster utilization and substitution patterns may better describe the physical demands of the starter, substitution, and bench roles throughout the season and contribute to how these roles should be trained throughout the season.

This study did not account for athlete participation affected by injury status throughout the season. Future studies should consider tagging the status of each player for each practice and match based on injury status (i.e. injured, modified, limited-participation) and account for modifications made to training. Players from each program, in this study, experienced non-time-loss injuries yet coaches modified training sessions for these players, including them as neutral or floaters during various games. This modification has been shown to reduce training loads for the player while keeping them involved in play[172].

CONCLUSION

The purpose of this study was to evaluate training load distrubutions throughout the NCAA men's and women's soccer in-season microcycle. Recognizing the influence of the NCAA's substitution rules on player utilization during matches, we suspected that three distinct roles of players would develop and that these roles would achieve different training loads throughout a season. After observing this trend, typically as a result of differences in match-day training loads, it is reasonable to suggest that sports science practitioners consider when and how they can provide bench and substitute players supplemental training load volume to prepare these players for the role of a starter should a promotion in player role occur. While this study was limited to two, single programs, practitioners should be able to apply similar methods to stratify player roles, monitor, and prescribe training loads accordingly. Future studies should consider minimal effective doses of training load volumes to physically prepare substitute and bench player roles for starter match demands.

CHAPTER 5: THE EFFECTS OF TEAM FATIGUE ON TECHNICAL PERFORMANCE DURING MATCHES IN NCAA DIVISION I WOMEN'S SOCCER

ABSTRACT

Approximately 10,000 players compete in NCAA Division I Women's Soccer. NCAA soccer is unique to professional soccer because of its looser substitution rules, allowing players to reenter into matches several times after being substituted out of the match. Professional soccer players demonstrate patterns of physical fatigue from first- to second-half reflective of reductions in high intensity run volumes. Furthermore, physical fatigue observed within these matches may attribute to technical performance reduction. Therefore, the purpose of this study was to measure physical performance fatigue and its effects on soccer performance indicators. A Division I Women's soccer program was evaluated in this study using GPS to aquire physical performance measures (total distance, high intensity running [HIR] distance, standing walking, jogging, high-speed running, very high-speed running, and sprinting distances). Match performance indicator data were acquired from a match analysis platform to provide key performance indicators for each half. Paired sample t-tests were used to evaluate reductions in team physical and technical performance between halves. Results demonstrated few indications of physical performance fatigue between halves as total distance and HIR distance were similar between halves. The program was observed to increase player utilization by one substitution from the first- to second-half. Evaluating match performance indicator data, the team allowed opponents more shots (mean diff: -1.87, $p < 0.001$), experienced a reduced possession percentage (mean diff: 4.20, $p < 0.04$), and reduced passing accuracy (mean diff: 2.95, $p < 0.05$). This study demonstrated that physical performance fatigue was relatively limited from the first- to second-half despite curtailed technical performance. This could reflect the increased incorporation of substitutions within a match, reducing technical skill across the program while maintaining physical fitness.

INTRODUCTION

The National Collegiate Athletics Association (NCAA) reports nearly 10,000 women's soccer players participate at its Division I level[164]. The implications of success at this level extend beyond championships as players have the opportunity to advance to professional soccer and capitalize on Name, Image, and Likeness deals. Historically, there has been a scarcity of women's soccer research, especially at the collegiate level[47]. While it may seem that research findings at the women's elite level are applicable to NCAA soccer, there are some contextual factors making competition in the NCAA unique to that of other elite soccer levels.

Two of the salient contextual factors are scheduling and season duration. These factors are particularly evident in the structure and schedule congestion of the NCAA competition season. During the season, matches are scheduled every two-to-four days, providing two-to-three matches per week. Professional soccer reports one-to-two matches per week[130], although there are instances of three games per week[33]. The NCAA season is much shorter than professional soccer seasons (spanning ~15-weeks compared to 40-weeks). These characteristics present unique challenges to incorporating training and recovery during the NCAA season for coaches and performance practitioners[42].

Within matches, the NCAA enforces its own set of rules, which are different than those set by FIFA, the international governing body. Player substitutions and clock management represent the major groupings of rule differences. In the NCAA, there is no limit to the number of substitutions per match. Players may exit the first half and reenter in the second half. During the second half, players may exit and reenter one time[43]. This is significantly different from FIFA's five substitution rule per match with no reentry. Another key difference between the NCAA and professional soccer pertains to how the clock is managed. Within professional soccer, the clock does not stop for the duration of a half. The referee is responsible for adding extra time based on the stoppages in play during a match. In the NCAA, the clock may stop for instances such as bookings, injuries, or goals[43]. As a result of these rule differences, collegiate players may play for shorter durations than professional players as a result of loosened substitution rules. Reentry at the collegiate level may allow players to return to the match fresher -increasing the intensity of play. Meanwhile clock stoppages could influence the total duration of time from the start of kick off to the final whistle within college matches -providing more time to accumulate training load volume. Therefore, coaches and practitioners should be cautious if expecting the same physical performances from their players as those reported in studies of professional, elite players.

Although differences in physical performance are suspected between NCAA and professional soccer, the study of match demands at the professional level can provide a comparison of the demands of the sport between these elite levels. Physical performance measures of locomotion are well-studied in elite women's soccer. These studies highlight that field players typically cover 10-11 km per match[39,93,96,115]. Women's elite soccer players are observed to cover 1.2-1.8 km of the total distance in a match at high intensity running velocities (> 15.0 km•h^{-1}), meaning the remainder of the distance is covered by walking or jogging[34,37]. Some studies indicate that this threshold for high intensity running should be lowered for female players to a > 12.5 km•h^{-1} threshold[51,173], suggesting the high intensity running could be greater than this during matches with reduced velocity thresholds. Regardless, the total amount of high-intensity running at the > 15.0 km•h^{-1} threshold has been observed to decrease significantly throughout matches[38,93]. While the reduction in high-intensity running performance can be attributed to a variety of factors such as game state or tactical adjustment[44], it may be a sign of chronic physical fatigue developing throughout the match[45,93].

While these findings suggest that physical fatigue is occurring throughout professional matches, as evidenced by high intensity running performances, it is unclear whether the same patterns will be observed in the NCAA. Provided the increased number of substitutions, coaches have greater flexibility to substitute a new player into a match if a player appears to be fatigued. As a result, one might expect the overall team's high intensity running distance to be similar between halves. In a single match, this may be true, but as players are exposed to the schedule congestion of the NCAA, they may enter games already fatigued.

Should physical fatigue during matches be observed in NCAA Women's soccer, the follow-up question is what effect this fatigue has on performance. Reilly (2008) argued that muscle fatigue experienced during matches may affect technical performance[109]. Several studies detail the effects of physical fatigue on technical soccer skills in isolated environments[140–142], but few studies have considered whether the anticipated decline in physical performance during a match contributes to skill execution.

Therefore, the purpose of this study was to examine differences in physical and technical performance between the first and second halves of NCAA soccer matches. We expected that teams would experience decrements to physical and technical performance between the first and second half of a match, similar to those observed in professional soccer.

METHODS

Participants

One team, composed of 29 NCAA Division I Women's soccer field players, was included in this study. Match data were collected from the Fall 2022 season by the program's sports scientist. A total of 18 regular season and 5 post-season tournament matches were included, while preseason exhibition matches were excluded from analysis. Demographic data (age, height, body mass) were collected for all field players. Players were classified according to their position role: defenders (DE), midfielders (MI), and attackers (AT) by the coaching staff at the start of each season. Goalkeepers were excluded from the analysis because of their unique positional demands. The use of players' match data for study was approved by the University's Institutional Review Board.

Each field player's match physical performance was monitored using Catapult Vector units (Catapult Vector, Catapult Sports, Melbourne, Australia). These units were worn in a compression garment that situates the unit between the player's shoulder blades. These units measure activity at 10-GHz using GPS and are reported to be reliable measurement tools of distance, velocity, and acceleration in team sport contexts[167]. Devices were turned on at least 15-min prior to warm up to allow satellite acqusition. During matches, the team sports scientist used Catapult Openfield (Catapult OpenField, Catapult Sports, Melbourne, Australia) to timestamp the start and end of each half, record the substitution occurrences, and manage the interchange of players to accurately record Field Time (the actual time players were actively in the match). The interchange also functioned to eliminate any additional physical activity performed as players warmed up before substituting into the match, limiting all physical performance to what was performed during the match. Additionally, the sports scientist used an annotation layer to timestamp every 15-min interval within the match. Timestamps were inserted for each interval following a running clock to align with the match performance interval dataset. Because the NCAA pauses the gameclock for events such as goals, cards, or weather events, some additional time beyond 45-min was observed in each half. Any added time observed was included in the final 15-min interval of each half to maintain consistency with the match performance dataset.

Post-match, all devices were collected by the team sports scientist. Data captured from these devices were transferred and processed using the Catapult Openfield software and uploaded to a cloud-based platform. Physical performance datasets were then exported for analysis in RStudio (version 2022.12.0+353).

Match physical performance measures reflecting the entire team (i.e., the sum of all individual field player performances) included (1) total distance covered (TD); (2) high intensity running distance covered (>12.5 km•h^{-1} , HIR); and (3) distances covered standing, walking, jogging, high-speed running, very high-speed running, and sprinting speed thresholds (STN, 0.0-0.7 km•h^{-1}; WAL, 0.7-7.2 km•h^{-1}; JOG, 7.2-14.4 km•h^{-1}; HSR, 12.5-19.0 km•h^{-1}; VHSR, 19.0-22.5 km•h^{-1}; SPR, ≥22.5 km•h^{-1}). These velocity thresholds are reported to be appropriate for elite female soccer players[51]. The match physical performances covered by the team as a whole were reported for 45- and 90-min time periods. While studies of professional soccer have evaluated individual player fatigue by assessing changes to individual physical performance throughout matches, the ability to substitute in the NCAA disallows the use of similar methods to assess fatigue[92,123]. Recognizing, however, a team always has ten field players in a match (barring a red card), the aggregate physical performance of the team may be evaluated for changes in physical performance throughout a match. Therefore, changes in performance between the first half and second half were reported as the mean difference. Mean difference calculates the difference in first half performance to second half performance. A positive mean difference would indicate a performance decline from first- to second-half whereas a negative mean difference would indicate a performance increase from first- to second-half[174].

Match performance indicators reflecting the entire team were sourced from the program's match analysis platform, Wyscout (Wyscout, Genoa, Italy). Match performance indicator datasets included full-match, half, and 15-min intervals. Wyscout provides all interval datasets assuming a running clock (no stoppages). Any added time recorded beyond 45-min was added to the final 15-min interval of each half. Match performance indicators were selected following the rationale of similar studies considering key performance indicators of match performance[136,175,176]. Match performance indicators included:

- Goals (G) – Represents the total number of goals scored[177].
- Goals Allowed (GA) – Represents the total number of goals scored by opponent.
- Expected Goals (xG) – Represents the probability of a shot resulting in a goal, accounting for the distance to goal, angle to goal, body part with which the shot was taken, and the type of assist or previous action[178].
- Expected Goals Allowed (xGA) – Reflects the total number of goals scored by opponent.
- Shots at Goal (Shots) – Represents the number of times a team attempts to score by intentionally directing a ball at their opponent's goal[177].
- Shots at Goal Allowed (ShotsA) – Represents the number of times an opponent attempts to score by intentionally directing a ball at their the team's goal.
- Ball Possession Percentage (BP%) – Represents the percentage of time individuals on a team are able to perform an action with the ball without an individual from the opposing team performing an action with the ball[179].
- Accurate Pass Percentage (AP%) – Represents the percentage of instances when a player passes the ball with any part of the body to a teammate instead of the alternative where the ball is received by the opposition or goes out of play[180].

- Offensive Duels Won Percentage (OD%) – Represents the percentage of duels won by the player possessing the ball when a challenge for the ball by an opposing player occurs[177].
- Defensive Duels Won Percentage (DD%) – Represents the percentage of duels won by the player not possessing the ball when a challenge for the ball by an opposing player occurs[177].

Statistics

Statistical analyses were performed in RStudio. The normality of distribution were confirmed for all continuous data using the Shapiro-Wilk's Test and Q-Q Plots. All data were presented as mean ± standard deviation. Paired t-tests were used to evaluate whether the team would experience a reduction in physical or technical performance between the first and second half. The statistical test was used to evaluate differences in match running performance and match performance indicators across the two halves of each match. When differences were observed, a Bonferroni adjusted *post hoc* test was performed to evaluate differences between each measure. Cohen's d were provided to evaluate the meaningfulness of each difference[181]. Trivial (<0.2), small (0.2-0.6), moderate (0.6-1.2), large (1.2-2.0), and very large (>2.0-4.0) classifications was used for ES magnitude[182]. Significance was set at $P < 0.05$ *a priori*.

RESULTS

Generally, physical and technical performance appeared unchanged throughout a match. Descriptive statistics of full match, first- and second-half physical performances are shown in Table 12. First- to second-half differences and the results of paired sample student *t*-tests are summarized in Table 13. Cohen's *d* mean differences are reported to demonstrate the change from first- to second-half performance (mean difference [diff] = $\text{Variable}_{\text{Half 1}} - \text{Variable}_{\text{Half 2}}$)[181].

Table 14: Descriptive Statistics from Match Physical Performance and Technical Performance

Characteristic	**Full Match**, N = 23[1]	**Half 1**, N = 23[1]	**Half 2**, N = 23[1]
Physical Performance Data Derived from Catapult			
Total Distance (m)	104,327 (4,854)	51,926 (2,728)	52,401 (2,810)
HIR Distance (m)	26,817 (2,773)	13,378 (1,356)	13,441 (1,702)
STN Distance (m)	797 (261)	356 (105)	441 (189)
WLK Distance (m)	39,460 (1,663)	19,390 (822)	20,070 (1,172)
JOG Distance (m)	37,218 (3,027)	18,791 (1,558)	18,427 (1,823)
HSR Distance (m)	22,017 (2,207)	11,073 (1,162)	10,945 (1,328)
VHSR Distance (m)	3,567 (553)	1,707 (251)	1,860 (359)
SPR Distance (m)	1,233 (350)	596 (208)	637 (202)
Field Time (min)	953 (41)	465 (17)	488 (29)
Player Utilization (#)	20.1 (3.8)	17.9 (3.5)	18.9 (3.5)
Match Performance Indicator Data Derived from Wyscout			
Duration (min)	97.4 (4.0)	47.4 (2.2)	49.6 (3.3)
Goals (#)	2.0 (1.7)	0.8 (1.0)	1.2 (1.2)
Goals Allowed (#)	0.7 (0.8)	0.3 (0.5)	0.3 (0.6)
xG (#)	2.2 (1.5)	0.9 (0.7)	1.3 (1.0)
xG Allowed (#)	0.9 (0.6)	0.3 (0.4)	0.5 (0.4)
Shots (#)	17.9 (7.5)	8.3 (4.4)	9.5 (4.3)
Shots Allowed (#)	9.2 (4.3)	3.7 (2.7)	5.5 (2.3)
Possesion Percentage (%)	60.8 (5.3)	62.7 (6.8)	58.5 (6.5)
Passing Accuracy (%)	77.3 (4.5)	78.4 (5.7)	75.4 (5.1)
Offensive Duels Won (%)	36.7 (4.7)	36.2 (7.7)	36.8 (6.7)
Defensive Duels Won (%)	64.7 (6.1)	67.1 (9.1)	62.7 (7.1)

[1]Mean (SD)

HIR: High-Intensity Run, STN: Stand, WLK: Walking, JOG: Jogging, HSR: High-Speed Run, VHSR: Very High Speed Run, SPR: Sprint, xG: Expected Goals

Table 15: First to Second Half Differences in Technical and Physical Performance

Variable	Difference mean value	95% CI Lower	95% CI Upper	Effect Size	Magnitude
Physical Performance Data Derived from Catapult					
Total Distance (m)	-474	-1,627	678	-0.18	negligible
HIR Distance (m)	-66	-643	511	-0.05	negligible
STN Distance (m)	-85.7*	-154.9	-16.4	-0.53	moderate
WLK Distance (m)	-679.7*	-1,179.0	-180.5	-0.59	moderate
JOG Distance (m)	363.6	-297.5	1,024.7	0.24	small
HSR Distance (m)	127.8	-375.4	630.9	0.11	negligible
VHSR Distance (m)	-152.8*	-273.8	-31.9	-0.55	moderate
SPR Distance (m)	-40.5	-133.1	52.0	-0.19	negligible
Field Time (min)	-22.1***	-32.0	-12.2	-0.97	large
Player Utilization (#)	-1.0	-2.6	0.6	-0.28	small
Match Performance Indicator Data Derived from Wyscout					
Duration (min)	-2.17*	-3.81	-0.54	-0.57	moderate
Goals (#)	-0.43	-1.03	0.16	-0.32	small
Goals Allowed (#)	-0.04	-0.32	0.23	-0.07	negligible
xG (#)	-0.37	-0.74	0.00	-0.43	small
xG Allowed (#)	-0.17	-0.38	0.04	-0.34	small
Shots (#)	-1.17	-3.04	0.70	-0.27	small
Shots Allowed (#)	-1.87***	-2.93	-0.81	-0.76	moderate
Possession (%)	4.20*	0.63	7.77	0.51	moderate
Pass Accuracy (%)	2.95*	0.18	5.72	0.46	small
Offensive Duels Won (%)	-0.58	-5.46	4.31	-0.05	negligible
Defensive Duels Won (%)	4.43	-0.27	9.13	0.41	small

*** p<0.001, ** p<0.01, * p<0.05
ES calculated using Paired Samples T-Test: negligible (d < 0.2), small (d = 0.2), moderate (d = 0.5), and large (d = 0.8)[181]
HIR: High-Intensity Run, STN: Stand, WLK: Walking, JOG: Jogging, HSR: High-Speed Run, VHSR: Very High Speed Run, SPR: Sprint, xG: Expected Goals

Little demonstration of physical performance decline was observed from the first- to second-half. Total distance and HIR distance covered tended to be greater during the second-half although differences in total distance and HIR distance between the first- and second-half were negligible. Moderate changes were observed for standing (mean difference [dif]: -85.66 m, $p < 0.05$), walking (dif: -679.74 m, $p < 0.05$), and very high-speed running distances (dif: -152.84 m,

$p < 0.05$) yet each of these physical performance measures improved from first- to second-half. Only jogging distance decreased in the second half, and this small change was determined to be statistically non-significant (dif: 363.63 m, *ns*).

Evaluating some of the factors which might contribute to physical and technical performance, some first- to second-half changes were observed. Notably, field time increased from the first- to second-half (dif: -22.09 min, $p < 0.001$) providing approximately 2.2 additional minutes per player during the second half. This was consistent with the match duration provided by Wyscout, which was moderately greater during the second-half (dif: 2.17 min, $p < 0.05$). A non-significant increase to player utilization was observed from the first- to second-half of the match (dif: 1.04 substitution utilized, *ns*).

In regard to technical performance, changes between first- and second-half performance were scattered. A greater but small number of goals (diff: -0.43 goals; *ns*), expected goals (diff: -0.37 xG; *ns*), expected goals allowed (diff: -0.17 xG allowed; *ns*), and shots (diff: -1.17 shots; ns) were observed in the second-half. There was a neglible increase in goals allowed from first- to second-half despite the moderate increase in shots allowed (diff: -1.87 shots allowed; $p < 0.001$). As these match performance indicators increased, a moderate decrease in possession percentage (diff: 4.20 %; $p < 0.05$) was observed between the first- and second-half. Small decreases were also observed for passing accuracy (diff: 2.95%; $p < 0.05$) and defensive duels won (diff: 4.43%; *ns*). Offensive duel percentage won was unimpacted from first- to second-half.

DISCUSSION

The purpose of this study was to identify patterns of fatigue in NCAA women's soccer and determine if physical fatigue impacts technical performance throughout a match. Unlike studies performed at the professional levels, changes in physical performance were not observed from the first- to second-half. The maintained physical performance from the first to second half may reflect adequate game and substitutition management in NCAA women's soccer. While maintaining physical performance throughout a match is important, maintaining high technical performance (i.e. short passes, successful short passes, tackles, dribbling, shots, and shots on target) has previously been identified relevant to successful match outcomes[36]. Identifying and addressing factors contributing to technical performance execution may improve match outcomes for women's soccer programs.

Over 23-matches, physical performance across the team was unaffected from first- to second-half. Most physical performance measures increased during the second-half. Several factors may explain why this pattern was observed. First, field time and total duration were observed to increase significantly during the second-half, lending more time for players cover distance at any speed. This could mean that many of the increases in physical performance observed in the second-half are contextually meaningless. For instance, a 40.54 m increase in sprint distance covered by the team was observed from first- to second-half. Scaled to the added duration and number of players on the team, this could mean that each player covered approximately 2.25 m additional sprinting in the second half which is relatively insignificant within the context of a match.

Second, substitution utilization increased in the second-half. Bansgbo (1994) discussed how a team can accommodate for reduced fitness amongst some of its players by relying on other players to carry out the physically demanding responsibilities of competition[153]. While Bansgbo is referring to the eleven players on the field, suggesting that certain players or positions work harder to accommodate for teammates, there are applications to NCAA women's soccer. Within NCAA women's soccer, greater substitution utilitization can introduce a greater number of players to a match, spreading the total work of the team amongst more players. Within this study, the aggregate performance of the field players was used to evaluate changes in physical performance throughout a match. This method reduced complexities associated with players changing positions or substituting in and out of the match, accounted for total work performed by any ten players in the match within a half (no red cards resulting in player ejections were observed in this study), and allowed for the comparison to team performance metrics such as possession percentage and passing accuracy percentage.

This, essentially, reduces the physical demands of players compared to those at the professional levels who play the entire 90-minutes. Furthermore, the introduction of a substitution can provide new energy within a match[183]. In professional soccer, provided the limited number of substitutions allowed a team, the timing of this substitution within a match is often based on tactical changes[183]. While tactical changes can still impact a substitution decision in NCAA women's soccer, a coach may utilize a substitution to provide a fatigued player an opportunity to recover before substituting the player back into a match -a strategy not afforded to professional soccer coaches. In doing so, the team, as a whole, can maintain a rate of physical work by reducing the impact of fatigue introduced by a single player. This could partly explain why physical performance was relatively unaffected from the first- to second-half.

Third, players substituted into a match may be less efficient, technically, than starters. Bangsbo (1994) presented that players with poorer technical ability must work harder physically throughout a match to regain possession[153]. Provided that more substitutes were used in the second half and several technical performance measures curtailed in the second half, it is plausible that the work-rate of the team increased to compensate for reduced technical performance execution.

Interestingly, while the utilization of substitutions throughout a match seems to mitigate physical performance fatigue, the use of substitutions also appeared to affect technical performance. During the second half, passing accuracy, possession percentage, and defensive duels won were reduced from the first half. The replacement of a starting player with a substitute has been suggested to be associated with a reduction in quality on the roster at the professional level[184]. Assuming similar quality reductions occur at the collegiate level, it would be reasonable to suspect that the overall technical quality of the team declines with each substitution, leading to passing inaccuracies or less success in one-on-one situtations. Rampini and colleagues (2009) suggested that technical performance and skill usually determine the outcome of a match moreso than physical fitness[36]. Coaches may want to use caution with substituting a player out of a match should a considerable drop-off in quality result.

Alternatively, the introduction of substitutions could be in response to a coach observing that physical fatigue is influencing the technical performance actions of starting players. At the professional level, players demonstrating higher physical fatigue exhibited less number of successful passes amongst a few other technical performance decrements[36]. Players at this level were also observed to become less involved in the match, meaning they were less often receiving and passing the ball[36]. It should be noted that physical fatigue was observed in players who competed the entire 90-minutes at this level[36]. In professional soccer, starters have exhibit signs of acute (within-game) physical fatigue (reduced work-rate) during the final 15-min of a match[34]. These signs were not observed within substitutions who, instead, covered 25% greater HIR and 63% greater sprinting during the remaining 15-min of the match[34]. Because not every player may be substituted out of a professional match, some starters will remain in the match for the final 15-min and likely exhibit acute physical fatigue. Throughout this duration of the match, physical fatigue may then impact technical performance[109]. Should this behavior be exhibited at the NCAA level, a coach can more freely elect to substitute a player demonstrating reduced technical performance, knowing that the player may reenter in the second half[173]. More work remains, however, on prompts a coach to substitute a player during a match.

Although the intent of this study was to assess physical and technical performance while accounting for the unique substitution rules in NCAA women's soccer, we recognize that this design had limitations. More specifically, by accounting for aggregate team performance, it was unclear whether individual physical or technical performance decrements would be observed. Future studies could consider limiting study to players who played the entire match or account for duration of time within the match each substitution bout. This study was also limited by inclusion of a single NCAA women's soccer program. The impact of this limitation is that this study is heavily impacted by the decisions made by the coach, the team's fitness and fatigue throughout the season, and the team's technical executition. The addition of more teams could better demonstrate physical and technical decrements throughout a match.

CONCLUSION

In closing, this study demonstrates that physical performance fatigue is relatively limited in NCAA women's soccer. Technical performance curtails in the second half which may be reflective of the increased utilization of substitutions during the second half. Coaches and sports science practitioners may find value in monitoring physical performance rates throughout the match and determining what physical performance decrement is significant enough to outweigh a technical dropoff resulting from a substitution.

CHAPTER 6: CONCLUSION

CONCLUSION

Soccer represents one the most popular sports globally, followed by over 5 billion fans[185] and played by over 240 million people. Leagues are represented internationally by youth to adult, recreational to professional, men's and women's, varying degrees of physical and intellectual ability, providing unique characteristics of the sport. Fiscally, the sport continues to experience tremendous growth. The top-20 money league clubs experienced a 14% growth from the previous year, accumulating 10 million Euro in revenue. These clubs are expected accrue an annual growth of 4% over the next five years[186]. Meanwhile, women's soccer experienced an average revenue increase near 61% within the top fifteen European clubs[187]. The international governing body, FIFA, reported over 7.5 billion dollars in revenue between 2019-2020[188]. As these clubs continue to grow, the economic impact of the sport should not go unnoticed. The sport is estimated to positively impact countries across Europe by 28.6 billion Euro through "implied benefits" such as education, integration, reduced crime rates, improved wellbeing, and reduced risk of health conditions[189]. Generally, the sport represents an enormously popular industry which extends beyond its enterainment value.

It should be no surprise, then, that scientific contribution has been made towards the sport. An average of nearly 1500 scientific publications for soccer are reported on Pubmed between 2019 and 2023, up nearly 25% from the previous five year window. Topics of research range from physiology and nutrition to injury prevention to diversity and inclusion to technology use within the sport. Perhaps as a result of the growing body of research and opportunity for scientific application for the development of players and teams, the sport has begun to embrace a formal role within clubs and organizations, the sports scientist[190].

One small sector of soccer is represented by the NCAA soccer system. The NCAA soccer system is composed of about 45,000 players across three divisions of men's and women's soccer[9]. This league, which is more selective and competitive than recreational soccer and yet, not as competitive as professional soccer leagues, is vastly different than other leagues throughout world. Season structure, schedule density, substitution, and clock rules differ from those set by the FIFA and other soccer governing bodies[43]. These differences present unique questions about how to train and prepare players throughout the season -questions which this dissertation was intended to address.

Before reviewing the findings of this dissertation, it is worthwhile to consider the value of research within the NCAA soccer context. Where the growth of soccer globally and financially signals for more research both at the professional and developmental levels for competitive advantage, the incentives for research in NCAA soccer are less apparent. One of the most publicized financial opportunities in college athletics is the compensation to student-athletes for Name, Image, and Likeness (NIL). Recent publication on NIL details some student-athletes are making over a million dollars in NIL annually[191]. At a glance, NIL appears to be a significant incentive for student-athletes to perform well. Unfortunately, these benefits are reduced approximately to $5,000 and $12,500 for men's and women's college soccer players, respectively[191]. These benefits do not necessarily signal for greater financial and research investment.

If immediate financial gain is limited amongst collegiate soccer players, an alternative rationale to support greater research within the NCAA soccer system could involve the role this system plays in developing players for professional soccer. Amongst other NCAA sports (i.e. football, basketball, baseball, ice hockey), college athletics represents a step in the development pathway to playing professionally in the U.S. The National Football League, for instance, selected all 259 draft picks from the NCAA in 2023[192] meaning that, in order to play professionally, players had to compete at the NCAA level. Women's soccer, similarly, drafted 47 of the 48 draft picks from the NCAA[192] suggesting that players seeking to play professionally should consider playing collegiately as part of their development pathway. On the men's side, however, the NCAA is considered in insufficient pathway for players seeking to play professionally[193]. Criticisms of the NCAA pathway include the duration of the season, the schedule density, the lack of supervision from league personnel, and the injury risk[193]. Overall, skilled players, in men's soccer, would be encouraged to remain in academy systems and forgo playing NCAA soccer[193]. In short, it appears that the NCAA represents a stronger development pathway for women's players.

Reflecting on financial and development aspects of NCAA soccer, there are several reasons to continue expanding on the current research in NCAA soccer. First, identifying the challenges to the unique construct of the NCAA season and the impact its rules have on players may highlight the need for beneficial changes to the sport so that players continue to develop, remain healthy, and transition to the professional level. Second, studying how players respond to these dynamics may provide valuable understanding to practitioners at the professional level for how to transition players from collegiate to professional soccer. Third, further research at the NCAA level may facilitate a better understanding of how to be more competitive for practitioners currently working within NCAA soccer. The remainder of this conclusion will attempt to address the contributions this dissertation has made in expanding upon current research in these ways.

Our first study examined the current state of the sports science role and evaluated how this role and its responsibilities are perceived by coaches and sports scientists within NCAA soccer. By surveying practitioners across all three NCAA divisions of men's and women's soccer, we began to develop an understanding of who is currently carrying out sports science in NCAA soccer. Unlike professional soccer, a coach was primarily responsible for carrying out the role of the sports scientist, not a formal sports scientist[15,16]. Practitioners who identified as sports scientists represented only Division I programs. As we inquired about training load monitoring throughout the season, most respondents reported the use of some type of training load monitoring tool. The information gathered by such tools often served the coaches in the training planning process. These findings speak to a major challenge within the NCAA regarding the use of sports science -there is an absence of practitioners formally trained in sports science to carry out the responsibilities of a sports scientist.

The significance of this study is twofold. First, we identified the lack of sports scientists in NCAA soccer. Second, we identified a couple types of practitioners that may benefit from sports science knowledge translation materials. A total of twelve sports scientists were identified in this study, even though designating an individual to serve in this role could serve to enhance player performance and keep players healthy throughout a season by tracking their internal and external work performed[15,17]. While its unclear why NCAA soccer programs do not have sports scientists on staff, it is reasonable to suggest that lack of financial resources represents a reason many programs do not sponsor a sports scientist on staff. Many respondents within this study cited this as reason for not having training load monitoring tools. To address this, we suggested programs begin collaborating within their university academic departments to carry out the daily monitoring practices and the interpretation of training load data. Future research should examine the potential for this symbiotic relationship, identifying the prevalence of university faculty equipped and interested in carrying out sports science for NCAA soccer programs when a sports scientist employed by the athletic department is unavailable.

In addition to identifying a lack of sports scientists in the NCAA soccer system, this study identified that sport coaches are often taking on the training load monitoring responsibilities of a sports scientist. This finding was surprising yet highlights sport coaches as a target audience for sports science education. This was consistent with another study aiming to identify how sport coaches can best use sports science information[73]. Strength and conditioning coaches were the second-most commonly identified practitioner responsible for monitoring and managing training loads. Similar to sport coaches, the incorporation of sports science topics such as training load monitoring and management in strength and conditioning curriculum may serve the soccer community well by better equipping these practitioners for these responsibilities. Future research should identify what the current knowledge base of sport coaches and strength and conditioning coaches is related to training load monitoring, fitness, fatigue, and performance management to better develop knowledge translation materials for this audience.

One of the major limitations of this study was the utilization of a survey to identify who was carrying out sports science and how. While we developed the survey to determine demographic backgrounds, program capabilities and practices, training and practice planning, and training load monitoring feedback, we were limited from learning anything more about our respondents preceptions and experiences beyond the scope of the questions. A secondary exploration of these perceptions in an interview format may reveal stronger themes pertaining to the use of training load monitoring and sports science within NCAA soccer programs.

Our second study examined in-season training loads, determining how training loads differed amongst roles unique to NCAA soccer. We identified from the beginning of this study that NCAA soccer differed from other soccer leagues based on the schedule density and the unique substitution rules. These differences introduced two factors that are not typically seen in professional soccer: shorter microcycles and three roles of players: starters, substitutions, and bench players. Within this study, we observed significant differences between starters' training load volumes throughout a season compared to substitution and bench players. These differences seemed exacerbated by the shortened microcycles throughout the season which limit programs from preparing substitution and bench players for match demands during training sessions.

The key implication of this study pertains to how different roles on a NCAA soccer roster are trained. Unlike professional soccer teams, the day following a match cannot represent the day within the microcycle when substitution and bench players make up the match day volume achieved by starters. To do so would place these (which?) players at risk of underrecovery for the upcoming match[30,31]. To better develop players and provide adequate recovery time for matches, the NCAA may want to consider adjusting its legislation regarding post-match training to allow substitution and bench players to perform top-ups, or high speed running bouts, immediately after a match to reduce the training load disparity. Additionally, the NCAA should consider the schedule congestion throughout the season -reducing the number of matches played each week to allow for more training time during microcycles and better recovery time between matches.

The key limitation of this study was the use of single NCAA men's and women's programs across a season. Future research should consider evaluating how players are developed and exposed to training loads throughout their NCAA careers. By capturing a single season, this study could not determine if players progressively develop greater training loads each year, preparing them for the demands of a starter towards the end of their student-athlete career. Investigating additional programs representing all three NCAA divisions would also help generalize these findings across the NCAA. Currently, this study represents a pair of single programs which are organized and managed by unique coaching staffs and composed of a specific cohort of players. Coach philosophies may fluctuate how players are utilized from program to program, therefore exposing player role groups to different training volumes throughout microcycles. Furthermore, coaching philosophy may change how training is conducted throughout the microcycle, increasing or decreasing training volumes during training sessions leading up to matches. Last, each program is represented by a unique cohort of players where different position groups may be more or lesser represented on the roster. This factor could limit how much recovery different position groups are afforded during training or the ability to substitute within a match.

Our third study evaluated physical and technical performance during NCAA women's soccer matches, paying special attention to physical performance fatigue and the effects fatigue had on technical performance from the first- to second-half. Generally, we saw limited evidence of physical performance fatigue measured by GPS technology throughout matches. While expecting to see the dropoff in total distance and high-intensity running distance covered from the first- to second-half, we observed that performance remained similar between the two halves. This may be the product of substitution utilization. Any time a coach observes signs of fatigue, they may elect to use a substitution off the bench, introducing 'fresh legs' to the match. Meanwhile, we observed some technical performance decrements throughout the match, but again, attributed these declines to the utilization of substitutions. We suspected that the quality of the player introduced to the match via substitution was poorer than that of the player on the field. This study demonstrated the applications sports science could make to both physical performance and strategy within a match.

The major limitation of this study was the representation by a single program. We cannot generalize our findings to other programs throughout the NCAA recognizing that roster makeup and coaching philosophy can change factors such as substitution utilization, overall team fitness, and team technical skill level and therefore may influence teams' demonstration of physical and technical performance fatigue from the first- to second-half. Future research should consider more programs and account for these factors as part of the study design. More specifically, future research may want to consider the preseason fitness levels of programs and how this attributes to physical fatigue throughout a match. The number of players and positional depth represented on the roster should be considered to determine how many players are available for substitution. The coach's historical use of substitutions may also be helpful in recognizing how players are prepared for matches throughout a season and the pacing strategies that may ensue. The teams and their opponents' quality (i.e. NCAA RPI, United Soccer Coaches Poll) could be worthwhile in determining which matches teams have to work harder. This study also did not account for a variety of contextual factors which could influence physical performance such as game state, location, weather conditions, formation, etc. These factors have been referenced in similar physical performance studies of professional soccer[38,44,98] and have yet to be studied thoroughly within NCAA soccer.

The purposes of this dissertation were threefold. First, we evaluated the perceptions of the application of sports science and the sports scientist role in NCAA soccer by NCAA Division I coaches and sports science practitioners. Second, we identified the distribution of training load throughout the in-season NCAA men's and women's soccer microcycle with respect to player role. Third, we measured fatigue throughout NCAA women's soccer matches and evaluated the relationship fatigue may have with soccer performance indicators. By addressing these purposes, we contributed understanding and practical applications which can improve the player and coach experiences within NCAA soccer by encouraging development and injury prevention, highlighting key differences between NCAA and professional soccer, and provide coaches a competitive advantage with effective strategy implementation.

On a broader level, this dissertation served a greater purpose of expanding on the current knowledge on NCAA soccer for both, men and women. As soccer grows globally in participation, it will be important to recognize that each version of the sport will inherit unique qualities. The responsibility of sports science researchers is to recognize these qualities and examine their impact on the sport.

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