RELATIONSHIPS BETWEEN LOWER EXTREMITY MOVEMENT QUALITY, INTERNAL TRAINING LOADS, AND INJURY RISK IN NCAA DIVISION I MALE COLLEGIATE SOCCER ATHLETES

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ABSTRACT

Tara Anne Condon: Relationships between Lower Extremity Movement Quality, Internal Training Loads, and Injury Risk in NCAA Division I Male Collegiate Soccer Athletes.
(Under the direction of Erik A. Wikstrom)

The purpose of this study was to examine the relationships amongst internal training loads (ITL), lower extremity (LE) movement quality, and injury risk in male collegiate soccer athletes. Fifty-two Division-I athletes consented to this study. Daily ITL were collected and tracked over the course of two consecutive seasons using a rated perceived exertion scale and session duration. LE movement assessments were performed in preseason using the Landing Error Scoring system (LESS), and were used to create two groups: poor movers (n=33,LESS ≥5), and good movers (n=19,LESS ≤4). Repeated measures ANOVAs and Chi Squares were utilized for analysis. Mid-season ITL were significantly lower compared to early ($p<.001$) and late ($p<.001$) season ITL. No significant differences in ITL were found between poor and good movers. Early-season injury risk was not influenced by movement quality or ITL but future large sample studies are needed in NCAA collegiate athletes.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I
INTRODUCTION

According to the National Collegiate Athletic Association's (NCAA) Injury Surveillance System (ISS),[1] participation in recognized championship sports has increased within the last ten years in both male (20%) and female (80%) athletics. This trend can also be seen in high school athletics.[2] With a rise in sports participation, there is also a subsequent rise in injuries.[3] In a 2007 epidemiology study of injuries in collegiate athletics,[4] researchers found an average injury rate of 16.4 incidents per 1000 athletic exposures (A-E) for regular season play. Another study found collegiate sports injury rates to be as high as 70.5 incidents per 1000 A-E for overuse injuries (women's field hockey), and as high as 190.0 incidents per 1000 A-E for acute injuries (women's soccer).[5] As participation in collegiate athletics continues to rise, researchers and sports medicine professionals can expect to see an increase in athletic exposures, and a subsequent increase in the number of injuries.[3]

Injury prevention and risk identification is a major role for clinicians in the field of sports medicine.[6,7] Current research has begun to identify certain risk factors that clinicians can manipulate in order to prevent future injuries.[6,7] These factors can be examined and modified during both the pre-season and regular season. One aspect of pre-season screenings is to assess the musculoskeletal and biomechanical abilities of an athlete, with the goal of identifying those who are at greater risk for injury.[7] Baseline testing and movement screenings (such as the Landing Error Scoring System (LESS)) are helpful means for clinicians to identify risk factors, such as limited range of motion (ROM) and poor biomechanics.[3,8,9] Research has shown that when these areas are poorly developed or limited – as identified during pre-season assessments – they can lead to abnormal training responses and increase injury risk.[10-12]

As a team transitions from pre-season into their regular season, other means of decreasing the possibility of injury include manipulating risk factors such as training load and recovery.[13,14,15] Training loads (TL) deal with the amount of work (whether it is too much, or too fast, or too soon) experienced externally and/or internally by an athlete.[16] External training loads (ETL), as defined by the International Olympic Committee,[17] refers to any external stimulus applied to an athlete that is measured independently of their intrinsic characteristics. An example includes parameters from a global positioning system (GPS), such as distance, velocity and acceleration.[14,18] Internal training loads (ITL) attempt to quantify the physical work performed by taking in account the physiologic impact experienced by the athletes themselves.[15] Rating of perceived exertion (RPE) scales are an efficient means of tracking ITL, which are used to determine how an athlete perceived their previous training segment.[14,15] Research has begun to show an association between TL and musculoskeletal injuries;[14,17,19–21] however, there is no single measure that has been identified to accurately quantify TL to predict injury risk.[14]

The intensity of a given exercise session (which is largely influenced by the ETL) will play a large role in the ITL experienced by an athlete. This gives clinicians the ability to use TL as a means of monitoring and altering an athlete's training prescription throughout a season in order to keep a proper balance between work and recovery.[15,22] Studies have shown that there is a significant amount of variability in the intensity present within practice and game activities for a particular sport. Matches and competitions have continuously shown to have a higher intensity compared to that of a regular training session.[4] Though further research is needed to validate TL as a means of representing how intensity impacts a training regimen, TL are beginning to give insight into the varying intensities of competition and its relationship to injury rate.[4,23]

Internal training loads (ITL) attempt to quantify the physical work and physiological response experienced by an athlete as a result of the external loads placed on them.[15,22] In order to obtain ITL, clinicians need to collect an exposure component and individualized response to activity. The exposure elements are extrinsic to the athlete, and are often recorded as the distance covered or duration of a particular training session. The majority of the current research examining ITL utilizes time for extrinsic loads.[15] The athlete's individual response to training has been measured in a variety of ways, some of which include heart rate (HR), lactate concentrations, biochemical markers, or RPE. Currently, the most employed method is to obtain an RPE via a modified Borg's Scale of Perceived Exertion.[15] By multiplying the athlete's RPE and length of a given session, clinicians can create a session RPE (sRPE) and track the trends in ITL of each athlete throughout a season.[25,26]

With a rise in the popularity of sports and incidence of injuries, there is an increased need to properly plan training sessions in order to effectively balance the loads placed on an athlete.[27,28] Future studies need to use a variety of TL (both external and internal means) as a combination of the two are more predictive and help to fully encompass the aspects of training that contribute to injury risk;[15,26] however, in a recent systematic review,[15] only 35 quality articles were identified for their work in examining the relationship between TL, injury and illness. Of these articles, the majority of the populations studied were rugby (n=12), cricket (n=5), Australian football (n=3), and soccer (n=3). Each study included a variety of skill levels (professional, elite, youth), different definitions of injuries and varying methods for obtaining TL.[15] This causes a decreased ability to compare findings and establish a clear and accurate relationship between TL and risk of injury.

Within the groups examined, none included a meaningful sample of NCAA collegiate athletes.[15] There is an increased need to include a wider variety of different leveled sports in TL research, helping to establish a more complete risk profile between different sports, gender and age groups.[15,29] In addition, there is limited evidence connecting pre-season LE movement assessments, in-season ITL, and injury risk. Thus, the purpose of this investigation was to examine the associations among relative and absolute rates of internal training load (ITL), LE movement quality, and risk of injury in NCAA Division I male collegiate soccer athletes during two traditional seasons.

Research Questions

Research Question 1: How do relative (ACWR) and absolute (total weekly sum) internal training loads change during an NCAA Division I men's collegiate soccer season?

Hypothesis 1a: Absolute internal training loads will vary throughout a collegiate soccer season with higher levels observed prior to post-season tournaments.

Hypothesis 1b: Relative internal training loads (ACWR) will vary throughout a collegiate soccer season with higher levels observed prior to post-season tournaments.

Research Question 2: Do NCAA Division I male collegiate soccer players with good versus poor movement quality exhibit varying relative (ACWR) and absolute (total weekly sum) internal training loads during their season?

Hypothesis 2a: Athletes who are defined as poor movers (LESS score [≥5]) will have higher average absolute internal training loads than athletes who are defined as good movers (LESS scores [≤4]).

Hypothesis 2b: Athletes who are defined as poor movers (LESS score [≥5]) will have higher average relative internal training loads than athletes who are defined as good movers (LESS scores [≤4]).

Research Question 3: Does the proportion of NCAA Division I male collegiate soccer players that incur an early-season low back or lower extremity injury differ significantly between those with good versus poor movement quality?

Hypothesis 3: Athletes who are defined as poor movers (LESS score [≥5]) will have a higher risk of sustaining an early-season low back or lower extremity injury compared to those athletes who are defined as good movers (LESS scores [≤4]).

Research Question 4: Does the proportion of NCAA Division I male collegiate soccer players that incur an early-season low back or lower extremity injury differ significantly between those with and without a high (>1.5) relative internal training loads (ACWR)?

Hypothesis 4: Athletes who experience a high acute:chronic workload ratio (ACWR ≥1.50) during the early-season will have a higher risk of sustaining a low back or lower extremity injury compared to those athletes experience a low acute:chronic workload ratio (ACWR ≤1.49) during the same time frame.

Definition of Terms

1) Training Load: the work experienced by an athlete during a given training and game session
2) Traditional Season: the time in which the team works towards an NCAA national championship. It begins on the first day of pre-season, and ends on the last game in the NCAA tournament. For NCAA Division I collegiate men's soccer, their NCAA national championship season occurs during the Fall semester.
    I. Early-Season: the first 1/3 (Week 1 through 6) of the entire traditional season

II. Mid Season: the middle 1/3 (Week 7 through 12) of the entire traditional season

III. Late Season: the last 1/3 (Week 13 through 18) of the entire traditional season

2) Injury: any musculoskeletal issue – which included any pain or disability suffered by an athlete during either a practice, competition or team organized event – that was reported to and evaluated by an individual on the sports medicine team.

Limitations

1) Multiple ATCs collecting study related sRPE and practice duration data
2) Psychological factors that influence athletes' sRPE response. These include but are not limited to the athlete's emotions and coach's indirect influence.
3) Collected LESS at one time point during the pre-season.
4) Lack of information regarding athlete's ITL prior to the start of pre-season

Delimitations

1) Only athletes from one Division I men's soccer program were utilized in this study.

CHAPTER II
LITERATURE REVIEW

Injury Incidence in Collegiate Sports

According to the NCAA Injury Surveillance System (ISS),[1] participation in recognized championship sports has increased within the last ten years in both male (20%) and female (80%) athletics. This trend can also be seen in high school athletics.[2] With a rise in sports participation, there is also a subsequent rise in injuries.[3] In a 2007 epidemiology study of collegiate athletes,[4] researchers found an average injury rate of 16.4 incidents per 1000 athletic exposures (A-E) for a regular season. Preseason practices had an injury rate of 6.6 incidents per 1000 A-E, which was upwards of 3-times higher than that of in-season practices.[4] Another study found collegiate sports injury rates to be as high as 70.5 incidents per 1000 A-E for overuse injuries (women's field hockey), and as high as 190.0 incidents per 1000 A-E for acute injuries (women's soccer).[5] As the participation in athletics continues to rise, researchers can expect to see an increase in the number of documented athletic exposures and injuries.[3]

Risk Factors for Injury in Collegiate Sports

Risk factors for musculoskeletal injuries can be broken down into two major categories: intrinsic and extrinsic risk factors. Intrinsic risk factors are individual to the athlete, and include things such as their gender, medical history, previous experience and imbalances in the musculoskeletal systems (such as strength, flexibility and neuromuscular control).[16]

Sex differences have been documented in a variety of injury patterns.[30] Females have been consistently found to have an overall greater injury rate than their male counterparts.[6,31,32] Multiple studies have found female athletes to have higher risk of sustaining an injury, specifically in intercollegiate athletics,[6] professional basketball players[33] and youth soccer players.[34] The differences are even greater when examining specific injury patterns, such as ACL ruptures and concussions.[35,36,37] Female athletes were found to be 9 times more likely to sustain an ACL tear,[37] and reasons have been connected to gender differences in biomechanics and muscle function.[38]

Research has shown that sex has demonstrated effects on movement screening performance scores, such as the Landing Error Scoring Systems (LESS).[39] In various studies performed on cadets and collegiate athletes, males and females have demonstrated differences in LESS scores. Males demonstrate on average higher LESS scores (5.34 ± 1.51)[40] and more sagittal plane landing errors[41] compared to the female group (4.65 ± 1.69; $p < 0.001$),[40] who demonstrate more frontal plane landing errors.[41]

Though gender differences can be a complicated issue to clinicians due to their non-modifiable causes, other intrinsic risk factors for injury – such as neuromuscular control, movement mechanics and muscle imbalances – have the ability to be corrected with clinical interventions. Various studies have connected diminished neuromuscular control to increased incident of injury.[10,11] Neuromuscular control is defined as a person's ability to operate their limbs while performing movement tasks. This is achieved by joint and mechanoreceptors sending afferent signals to the brain to create a movement strategy. Inefficient or bad movement strategies result in mismanagement of forces throughout the body, leading to structures being overloaded and overstressed.[42] Clinical tests for assessing a patient's movement strategies have been developed and studied for their validity and reliability to identify poor movers. Some tests that have been proven to be successful include the Functional Movement Screen,[42,43] Star Excursion Balance Test[42,44,45] and the Landing Error Scoring System test.[42,46]

The FMS, or Functional Movement Screen, is a real-time assessment tool that incorporates the whole body's ability to move with the goal of identifying imbalances based on observed asymmetries and dysfunctional movements.[43,47,48] Most commonly performed using an overhead squat, the FMS's major limitation is the lack of sport specific movements included in the assessment.[49] Though compound movements (squatting, lunges, etc.) can give clinicians insights into possible underlying impairments, dynamic movements place a greater demand on the body, and these may be missed without further assessment.[42,49] Other assessment tools have been studied that examine more dynamic movements, such as the Star Excursion Balance Test (SEBT). The SEBT is a clinical tool that assesses a person's ability to maintain balance while performing a reaching task.[44] It provides a challenge to the body's sensorimotor system, and tests muscular strength, joint range of motion and a patient's ability to balance.[44,45] Though proven to be a reliable and valid predictor of lower extremity injury,[50,51,52,53] the SEBT does not provide evidence about an athlete's movement strategies during sport-specific activities.[42]

The Landing Error Scoring System (LESS) is another clinical movement screen that has been widely studied for its ability to detect athletes at greater risk for lower extremity injuries.[46] The LESS uses a basic jump-landing task to challenge a person's ability to control and move their body in space. First introduced in 2010, the LESS test grades an athlete's ability to perform a jump-landing task based on a 17-error scale.[8] The LESS can be used by both novice and expert clinicians, with an ICC of 0.84; however, this validity is dependent on the type of error assessed during the jump landing task.[39] Researchers suggest that errors not valid should be reduced from the current LESS scoring criteria.[54] The LESS-RT (10-errors compared to the LESS 17-errors) has been developed and validated as a quicker assessment of movement quality.[39] Further studies should consider examining the associations of the LESS.

Specific movement patterns found during a LESS have been associated with increased risk of lower extremity injury. These limitations include decreased hip, knee and trunk flexion in combination with increased rotational and valgus forces at the knee.[42,55–58] The LESS includes a multiplanar biomechanical assessment and allows a clinician to screen for the known movement dysfunctions.[11,42,59–61] Some limitations of the LESS is that testing is performed using standard video cameras, and the assessment of performance is based on a single type of jump landing (drop vertical jump);[42] however, studies have established the LESS as a sensitive and reliable clinical tool for evaluating an individual's movement strategies,[42,46] and research suggest that clinicians need to use a jump landing screen to identify those athletes who are at greater risk of lower extremity injuries.[7,38]

Another intrinsic risk factor for injury is the onset of fatigue. Fatigue developed during a given training session is connected to decreases in performance and higher incident rates of lower extremity injuries.[62–64] Fatigue driven imbalances in neuromuscular control have been connected to decreased joint stability, and increased risk of injury.[60,65] The body has natural protective mechanisms against injury, such as muscle stiffness. Muscle stiffness is developed through active and passive tissue tension. Fatigue reduces the body's ability to maintain muscle stiffness during exercise. Without the ability to produce proportional muscle stiffness with relation to the external loads, the body has a limited potential to create dynamic joint stability, leading to an increase risk for injury.[66] Insufficient balances between training sessions and recovery periods result in a greater cumulative fatigue in athletes. Greater levels of cumulative fatigue increase the incidence of negative adaptions to training, such as injury and illness.[17,15] As clinicians, it is pertinent to introduce means that quantify fatigue and training load.

With regards to player experience, studies by Pasque and Hewett[3,9] demonstrated that more experienced high school wrestlers had a higher injury risk than those with less experience. The researchers stated that the more expert wrestlers had more playing time (i.e. more exposures and training load), a greater number of injury history incidents, and were more aggressive than the less experienced athletes.[3,9] In comparison, Emery and his team did not find any significant difference for injury risk between U16 and U18 soccer players.[3,67] The variations in results may be a consequence of the major differences in physiological requirements, skills and style of the diverse sports.

In comparison to intrinsic factors, extrinsic risk factors for injuries include (but are not limited to) the type of sport, external environment, surfaces, and training errors.[16] Relative risk of an acute injury can be determined by understanding the extent of player contact within a given sport.[68] With participation in collision sports (boxing, lacrosse, football) and contact sports (basketball, soccer), there is an accepted risk of injury due to the nature of the sport, and dangers associated with training activities.[68] Collision sports have a higher injury risk due to the larger forces, and increased player contact that occur during the practices and games.[4,68]

Other factors involved during a practice or game that can lead to an increase risk of injury include the environment, playing surface and structure of the given session (i.e. workload placed on the athlete). Environmental factors, such as heat and humidity, can play a role in injury incidents.[69] A higher level of humidity limits the body's ability to thermoregulate, increasing the risk for heat related illnesses.[69] Meyers and Barnhill examined the differences in injury rates between artificial turf and natural grass in football and reported that they exhibited unique injury patterns.[70] Lastly, training errors deal with the amount of load (whether it is too much, or too fast or too soon) placed on an athlete.[16] Training load can be defined as either internal or external[15] Research has shown relationships between training load and musculoskeletal injuries,[15] however further research is needed to validate the findings.

Training Loads

As a team transitions from pre-season into their regular season, clinician's use other measures to monitor injury risk. By examining the training loads (TL) experienced during practice and game activities, clinicians can better understand the relationship and balance of training and recovery. The intensity of a given exercise session will play a large role in the TL experienced by an athlete. This allows clinicians to use TL as a means of monitoring stress throughout a season, and to make recommendations regarding the alteration of a training prescription in order to keep a proper balance between work and recovery.[15,22]

Studies have shown that there is a significant amount of variability in the intensity present within game and practice activities for a particular sport. Matches and competitions have continuously shown to have an higher intensity compared to that of a regular training session.[4] Though further research is needed to validate TL as means of representing how intensity impacts a training regimen, TL are beginning to give insight into the varying intensities of competition and its relationship to injury rate.[4,23,71] In a study done by Gabbett,[71] TL data was collected daily for three rugby teams using a modified RPE scale[72] over the course of one season. The study found a high correlation between incidence of injuries and intensity of a match.[71] Other studies[73,74] also agreed with Gabbett's work,[71] giving support to suggest that changes in intensity can lead to an increase in injury rates.

Training load can broadly be defined as the internal or external work experienced by a person.[15] External training load (ETL), as defined by the International Olympic Committee,[17] refers to any external stimulus applied to an athlete that is measured independently of their intrinsic characteristics. Examples of ETL include pitching in baseball,[75,76] shots on goal in water polo,[77] or the distance covered by a rower.[78] This form of training load is primarily utilized in sports with repetitive actions, or ones where there is a continuous sporting action.[15] Studies have found a moderate relationship between ETL and illness. Out of the 8 studies that have examined the interaction, 75% found a positive relationship between ETL and illness.[15]

When examining the relationship between ETL and injury, there is strong research supporting the need to quantify ETL in sports that are upper extremity dominate or include activities such as throwing, pitching and/or bowling.[29,79] Associations have been found between soreness in elite female water polo players and number of shots,[77] as well as in baseball players and the number of pitches.[75,76] This relationship has not been studied within lower extremity dominant or field sport athletes, such as kicking in soccer or passing in lacrosse. Mixed results have been found when examining the relationship between distance ran and injury risk. Fricker et. al[80] found no relationship between total distance and injury in middle distance runners; however, current evidence is beginning to show that injury risk is not about the total load experienced by an athlete (i.e. total distance ran), but rather related to the relationship between changes in training load.[20]

It is important to note that ETL (such as number of balls bowled or pitches thrown) do not include all aspects of a training session that contribute to the demands experienced by an athlete.[15,81] Quantifying ETL will only represent a portion of an athlete's total loads, which leads to a limited percentage of TL to be considered when examining injury risk.[82] When examining field sport athletes (such as soccer, lacrosse or field hockey), examining ETL – such as the number of passes or shots – can be impractical or impossible for a researcher to do accurately. Other examples of ETL, such as distance ran, acceleration of an athlete, etc., can be tracked using global positioning systems (GPS). Global positioning systems have shown to be beneficial for assessing the ETL of an athlete;[83–85] however, these systems have not been proven to be valid assessments of an athlete's total load and require resources that clinicians may not have access to.[86,18,87] Future studies need to include all aspect of training, both external and internal to the athlete, as well as means of tracking TL that are more clinically practical.[15]

Internal training loads (ITL) attempt to quantify the physical work and physiological response experienced by an athlete as a result of the external loads placed on them.[15,22] This allows for a larger percentage of the athlete's workload to be included when determining risk of injury. In order to obtain ITL, clinicians need to collect an exposure component and individualized response to activity. The exposure elements are extrinsic to the athlete, and are often recorded as the distance covered or duration of a particular training session. The majority of the current research examining ITL utilizes time for extrinsic loads.[15]

The athlete's individual response to training has been measured in a variety of ways, some of which include heart rate (HR), lactate concentrations, biochemical markers, or a rating of perceived exertion (RPE). Currently, the most employed method is to obtain an RPE via the Borg's Scale of Perceived exertion.[15] By multiplying the athlete's RPE and length of a given session, clinicians can create a session RPE (sRPE) and track the trends in ITL of each athlete's throughout a season.[25,26] Both ITL and ETL are limited in the sense that they do not account for the type of training the athletes partake in, such that short, intense sessions will be equal to that of a long, low-intensity event.[15]

When analyzing the ways in which injury or illness are related to TL, clinicians can either look at the absolute or relative TL experienced by an athlete.[15] Absolute training loads are defined as the sum of all the training loads (whether they are ETL or ITL) in a given training session, a particular set of training sessions, or over a given period of time (such as the sum of training loads throughout one week of training).[15] Relative training loads looks at the trends that occur in training, especially expressing the change as a percentage or ratio.

Clinicians have examined the percentage increase from week to week, as well as the ratio of recent and past loads, which is referred to as the acute-to-chronic (acute:chronic) workload ratio (ACWR).[26] The acute phase of training is a period of 'fatigue' that is sustained in the present time (absolute TL from one day, or absolute TL from one week). The chronic phase refers to the 'fitness' period that occurred in the weeks prior to the current (or acute) phase, most commonly using the last month (i.e. prior 4 weeks).[26,88] This analysis of training loads has been the most utilized and is the recommended way to examining the effects of training load on an athlete.[15] Figure 2.1 displays an example of a regular season absolute training load and the acute:chronic workload ratio (ACWR) for one team.

Both absolute[75,76,89] and relative loads[29,81] have been shown to be related to injury occurrence. However, relative workloads allow for a comparison of athletes of different levels by examining the ratio of change versus the entire sum. Relative workloads also demonstrate a higher predictive capacity of determining injury risk than absolute loads.[15,29] Findings from a recent systematic review,[15] suggest that injury risk is better determined by examining the magnitude of the ratio between the acute and chronic load, where acute load is defined as the absolute load of the last 7 days, and the chronic load is defined as the average of the absolute weekly TL from the month prior.[79]

Summary

Injury prevention is a major role for clinicians in the sports medicine field. Current research has begun to identify the modifiable risk factors that can be subsequently manipulated in order to prevent future injuries. Pre-season examinations are required to include musculoskeletal and biomechanical assessments in order to detect those who are at a higher risk for injury.[7] Baseline testing and movement screens – such as the FMS, SEBT and LESS – are popular means of helping to identify these factors.

With a rise in the popularity of sports and incident of injuries,[1,2,3] there is an increase need for clinicians to monitor their athlete's training and recovery. ITL have been proven to be a valid means of quantifying an athlete's response to the loads placed on them throughout practice or game activies.[15,22] By collecting a daily ITL, clinicians can keep a balance of the loads placed on an athlete, and help to decrease the risk of injuries that occur due to overtraining.[27,28,85] In a recent systematic review,[15] only 35 quality articles were identified for their work in examining the relationship between TL, injury and illness. Of these articles, the majority of the populations studied were rugby (n=12), cricket (n=5), Australian football (n=3), and soccer (n=3). Each study included a variety of skill levels (professional, elite, youth), different definitions of injuries and varying methods for obtaining TL.[15] The existing variety demonstrates the generalizability of TL but limits our ability to compare findings and establish a more complete risk profile in any given set of athletes.[15,29]

Currently, no data exists on a meaningful sample of NCAA collegiate soccer atheltes.[15] Thus, one of the goals of this study is to create a greater profile of TL by studying a population that has yet to be clearly monitored. With over 460,000 students participating in NCAA collegiate athletics every year,[1] it is important to begin to establish the trends in ITL that occur in specific populations in this demographic. In addition to being limited in NCAA collegiate athletes, the literature fails to show the relationship between ITL and preseason biomechanical assessments. TL are often studied independently using univariate analyses, and not examined for any potential interrelationships with other injury risk factors. There is a lack of evidence connecting pre-season risk factors and in-season TL. There is also no clear understanding of how athletes who are pre-disposed to injury experience loads compared to those who are not at greater risk. In athletes' who are identified as "poor movers", they can be hypothesized to work harder compared to their teammates during a given practice or game activity, and thus experience difference TL. As part of this study, one of our goals is to expand the body of evidence examining injury risk factors, and begin to understand how intrinsic risk factors manipulate ITL.

Internal training loads (ITL), measured using an RPE scale and duration of training, is a relatively easy method of monitoring an athlete during their season. They are cost effective and allow a clinician in any setting to improve the performance of their athletes. It is important for research to validate clinical tools that are both practical and resourceful at all levels of sport. ITL have been widely studied, and are beginning to show their diverse applications. This study will only expand on what clinicians know about how an athlete responds to the demands of their sport and what causes a decrease in performance and/or injury to occur.

CHAPTER III
METHODOLOGY

Participants

One NCAA Division I male collegiate soccer team was recruited during their Fall 2016 and Fall 2017 season. Fifty-two athletes volunteered to allow their TL data to be examined for this project. All participants received a thorough explanation of the study – which included the risks and benefits – prior to consenting. The university's Institutional Review Board approved this project. Only athletes who participated in team activity during the season being studied were included for analysis. Athletes were removed from each season's analysis if they missed at least six weeks of play, had a season ending injury, and/or would not be participating in their team's current season. Each season included a different set of athletes, with only 20 individuals completing both seasons. Summary statistics for the athletes' demographics may be found in Table 3.1.

Definition of Injury

For the purpose of this study, we utilized an adaptation of the Gabbett et al[71] injury definition. An *injury* was defined as a musculoskeletal issue to the lower extremity or low back – which included any pain or disability suffered by an athlete during either a practice, competition or team organized event – that was reported to, evaluated, and had a treatment plan initiated by an individual on the sports medicine team. Any general medical, dermatological issues (infections, abrasions, lacerations, etc.), upper extremity

(UE), cervical, thoracic, and head injures, as well as contusions were not included for this study. The sports medicine team included: certified athletic trainer(s), supervised athletic training student(s), and team physician(s). All members of the sports medicine team are employed by UNC-CH to provide injury assessment, prevention and treatment services to the student-athletes.

Pre-Season Measures

Demographics

Demographics - such as age (years), height (m) and weight (kg) – were taken during the team's pre-participation examinations (PPE) as part of their standard care in the beginning of the Fall 2016 and Fall 2017 seasons (Table 3.1).

Landing Error Scoring System (LESS)

The LESS was used as a pre-season screening tool in order to assess the athlete's biomechanical movement quality. Three successful trials were taken at the start of the Fall 2016 and Fall 2017 seasons. The LESS is a jump-landing task that requires the athletes to perform two jumps: a horizontally jump from a 30 cm box to a distance that is equal to 50% of the athlete's height, followed by a maximum vertical jump.[8] X-Box Kinect sensors were utilized instead of standard video cameras. A specialized online software, Physimax, was used to analyze jump-landing performance. This has been showed to be a reliable means of capturing accurate LESS performance scores.[90]

To complete the LESS, the athletes first started in front of a 30 cm box - in order to allow the X-Box Kinect sensors to recognize their limbs – prior to stepping onto the box. Once the athletes were in position, researchers cued them to jump forward past the marked line (representing 50% of their height), and then straight up into the air as high as they were able to after landing.[8] Researchers did not give any feedback or make adjustments on biomechanics unless the athletes were not able to perform a successful jump. Padua et al[8] described a successful jump as an athlete being able to (1) jump off the box with both feet; (2) initially jumping horizontal, not upwards towards the marked line; (3) initially landing with both feet; (4) completing a maximum vertical jump directly after landing in a fluid motion. Athletes were allowed one practice trial to familiarize themselves with the task, followed by three successful jumps.

The mean of the three trials were used to calculate the LESS score using the 17 jump-landing characteristics. We recorded the overall LESS score, as well as the individual errors that were made during the jump-landing task. Based on their LESS score, athletes were placed into one of two movement quality groups – good mover and poor mover. We utilized a modified version of the four groups originally described by Padua et al.[8] For our study, a good mover was an athlete who demonstrated a LESS score ≤ 4, whereas a poor mover has a LESS score ≥ 5. This cutoff score was determined based on a previous study done by Padua et al,[38] where they examined soccer athletes and determine those with a LESS score of 5 or higher were at greater risk for injury. This study was mainly examining risk for ACL injury; however, due to the limited data on LESS cutoff scores for soccer players, this score was used for the purpose of this study.

In-Season Measures

Internal Training Load (ITL)

Training load, as previously defined in Chapter I, is defined as the work experienced by an athlete during a given training or game session. For the purpose of this study, ITL will be used to track the athlete's workload throughout their regular season. This method of quantifying ITL involves collecting a daily rating of perceived exertion (RPE) after an exercise bout in order to obtain a *session RPE* (sRPE).[72] For our study, we used a modified Borg's Scale of Perceived Exertion (Figure 3.1). Originally described by Foster et al,[72] sRPE represents an overall rating of the intensity for the complete training session. The sRPE will be a whole number between 0 and 10 and multiplied by the duration of the training session or game. It will be recorded in arbitrary units (AU). *Duration of the training sessio*n is defined as length of time (measured in minutes) between the start of warm ups, until the end of playing, and will be recorded to the nearest minute. A normal practice ends during a final meeting with the head coach; however, if certain players stop early for any reason, it was noted. *Duration of a game* will be recorded as the number of minutes calculated by the university's sports administration personnel and documented on the box score of the game.

Training loads was only collected for team-organized activity. For days that the team did not have any team organized practice, game or weight session(s), both sRPE and duration will be recorded as a zero. sRPE was taken within 30 minutes after the end of a soccer event. Any data that was missed during this time frame was collected as soon as possible by one of the certified athletic trainers.

Training Load Data Reduction

ITL data was collected as a whole integer on the RPE scale from 0-10, and duration was recorded to the nearest minute. This method of quantifying ITL involved multiplying the athlete's RPE (1-10) by the duration of the session (in minutes) to give a daily ITL (AU). For every week, seven daily loads were collected and summed together to give one absolute weekly ITL per player. The absolute weekly ITL will be used to create an acute:chronic workload ratio (ACWR), which is the ratio between the acute load (current absolute weekly ITL) compared to the chronic load (average of the prior four week's absolute weekly TL). ACWR were calculated starting five weeks into each season, due to the lack of ITL data from the team during the off-season. Each season was 18 weeks long, and was divided into three 6-week segments: early-season (Week 1-6), mid-season (Week 7-12), and late-season (Week 13-18).

Documentation of Injuries

Following each season, low back and LE injury data was extracted from each participant's electronic medical record. A standardized data collection form was used to record information (date of injury, body region, type of injury) pertaining to each injury. For this investigation, only the date of injury was used for analysis while all other information was recorded for descriptive purposes only.

Procedures

Prior to the start of the season, the team was educated on the purpose and means of collecting an sRPE, to decrease the variance due to misunderstanding of training loads.

As previous described by Gabbett and Jenkins,[25] athletes were shown the scale (Figure 3.1) after each session and asked 'how did you feel today's [training session, lift, game] was, from start to finish?', giving the ATC an estimation of intensity.[72] ITL were recorded by the ATCs every session, from the first day of pre-season until the final match of the NCAA championship season. This method was utilized for Fall 2016 and Fall 2017 seasons. Values were collected within 30 minutes of the end of each given session and recorded as whole integers. In addition to sRPE, the team's ATCs were also held responsible for collecting the duration of a given training session, as previously defined. The ITL was recorded manually on paper and later organized on an electronic master dataset. Data was de-identified when analyzing the data at the end of each season.

Statistical Analysis

This was an observational study that examined the relationships between jump-landing biomechanics, in-season metrics of quantifying intensity (absolute and relative ITL) and incident of injury. Multiple statistical analyses were run to answer the research questions proposed.

Research Question 1

How do relative (ACWR) and absolute (total weekly sum) internal training loads change during an NCAA Division I men's collegiate soccer season?

Separate one-way repeated measure ANOVA were used to examine potential differences in absolute and relative ITL experienced by collegiate soccer athletes among the early-, mid-, and late-season segments. Post-hoc comparisons will be run when appropriate to determine the location of statistically significant findings. Alpha level was set to .05.

Research Question 2

Do NCAA Division I male collegiate soccer players with good versus poor movement quality exhibit varying relative (ACWR) and absolute (total weekly sum) internal training loads during their season?

Separate two-way repeated measure ANOVA were used to determine significant difference between good and poor movers during season segments. For both absolute and relative ITL, the within-subject variable used was time. The between-subject factor was movement quality group, as previously defined. Post-hoc comparisons will be run when appropriate to determine the location of statistically significant findings. Alpha level was set to .05.

Research Question 3

Does the proportion of NCAA Division I male collegiate soccer players that incur an early-season low back or lower extremity injury differ significantly between those with good versus poor movement quality?

A Pearson's chi-square analysis was run between movement quality group and injury status (injured or healthy) in the early season segment. A significance level of 0.05 was used.

Research Question 4

Does the proportion of NCAA Division I male collegiate soccer players that incur an early-season low back or lower extremity injury differ significantly between those with and without a high (>1.5) relative internal training loads (ACWR)?

A Pearson's chi-square was run between ACWR group and injury status (injured or healthy) in the early-season segment. A significance level of 0.05 was used. For group, athletes that exhibited an ACWR greater than or equal to 1.50 at least once during the early-season were placed in the high ACWR group. An athlete whose ACWR during the early-season never exceeded 1.49 was placed in the low ACWR group.

Table 3.1. Participant Demographic Information

	n	Height (m)	Weight (kg)	Age (yrs)	LESS Score	Injured	Non-Injured
Fall 2016	23	1.82 ± .07	75.65 ± 8.22	19.70 ± 1.33	5.57 ± 1.83	15	8
Fall 2017	29	1.80 ± .04	75.82 ± 5.20	19.72 ± 1.31	4.79 ± 1.50	17	12
Combined	52	1.81 ± .06	75.74 ± 6.64	19.71 ± 1.30	5.13 ± 1.68	32	20

Rating of Perceived Exertion (RPE Scale)	
10	Maximal
9	Really, Really, Hard
8	Really Hard
7	
6	Hard
5	Challenging
4	Moderate
3	Easy
2	Really Easy
1	Rest

Figure 3.1. The modified Borg's Scale of Perceived Exertion used to collect the sRPE.

CHAPTER IV
RESULTS

Research Question 1

How do relative (ACWR) and absolute (total weekly sum) internal training loads change during an NCAA Division I men's collegiate soccer season?

A Mauchly's Test of Sphericity demonstrated no significant departure from normality in the absolute ITL load data were (p=0.695). Analysis of absolute and relative ITL across parts of season took place using a one-way repeated measures ANOVA. Differences were noted over time between the early- and mid-season ($p < .001$), early- and late-season ($p < .001$), and mid- and late-season average absolute TL ($p < .001$). The ACWR was normally distributed ($p = 0.605$) but the ACWR did not differ across the season segments ($F_{(2, 90)}=0.367$, $p =.694$). The average ACWR and average weekly absolute TL for the combined two seasons are displayed in Figure 4.1 and Table 4.1.

Research Question 2

Do NCAA Division I male collegiate soccer players with good versus poor movement quality exhibit varying relative (ACWR) and absolute (total weekly sum) internal training loads during their season?

The majority of participants were considered poor movers (n=29, mean LESS score= 6.13 ± 1.24) while the remaining 18 participants were good movers (mean LESS score= 3.39±0.70). Analysis of absolute and relative ITL across parts of season between the two groups took place using a two-way mixed measure ANOVA. Absolute TL were normally distributed (p=0.821) and differed over time ($F_{(2\ 90}$ =48.978, between the early- and mid-season ($p < .001$), early- and late-season ($p < .001$), and mid- and late-season average absolute TL ($p < .001$). A group main effect was not present ($F_{(1,45)}$=0.889, p=0.351), and no Group x Time interaction was found ($F_{(2,90)}$ =1.773, p=.176). The ACWR also was normally distributed (p=0.752). No Time ($F_{(2,88)}$=0.558, p=0.574) or Group ($F_{(1,44)}$=1.573, p=0.216) main effect were identified. Similarly, no Group x Time interaction was identified ($F_{(2,88)}$=1.834, p=0.166). Figure 4.2 and Figure 4.3 illustrate group by time breakdowns while Table 4.2 displays the descriptive data.

Research Question 3

Does the proportion of NCAA Division I male collegiate soccer players that incur an early-season low back or lower extremity injury differ significantly between those with good versus poor movement quality?

A total of 16 first-time injuries occurred during the early part of each of the two-seasons, which represents 50% of all observed injuries. While the majority of the early season injuries (n=11, 68.75%) where sustained by poor movers, the proportion of good verses bad movers who sustained an early-season injury did not differ (p=0.598). Figure 4.4 illustrates the breakdown of injuries based on movement quality during the early-season segment. In the early part of the season, 11 poor movers (33.33% of poor movers) sustained a lower extremity or low back injury, relative to 5 good movers (26.32% of good movers). A breakdown of the injuries that occurred throughout the two seasons are included in Table 4.3.

Research Question 4

Does the proportion of NCAA Division I male collegiate soccer players that incur an early-season low back or lower extremity injury differ significantly between those with and without a high (>1.5) relative internal training loads (ACWR)?

In early-season (week-1 through week-6), one healthy player (out of a total 34) had an ACWR that was greater than or equal to 1.5 relative to zero injured players (out of a total of 12). This was not significantly different between the groups (p=.548). The Pearson's Chi square was found to have a low cell count, indicating that it was not adequately powered, and thus a valid analysis was not possible at this time. Figure 4.5 illustrates the breakdown of ACWR based on injury status during early-season.

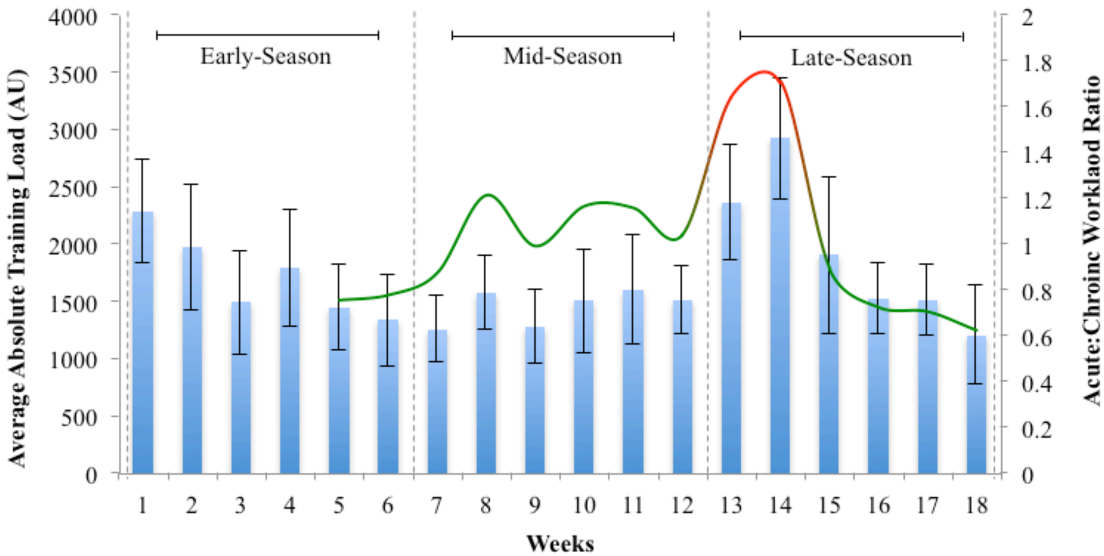

Figure 4.1. The bar graph displays the weekly absolute training loads averaged across all players both seasons. The line graph on top displays the acute:chronic workload ratio averaged across all players from both seasons. Each season is broken down into 6-week blocks, which correspond, to "Early-Season", "Mid-Season" and "Late-Season".

Table 4.1. Descriptive Statistics for Part of Seasons - Average Weekly Absolute Internal Training Loads and Average Acute Chronic Workload Ratio

		Average Weekly Absolute TL			Average ACWR		
	Weeks	Mean	SD	n	Mean	SD	n
Early-Season	1-6	1747.80	536.85	46	0.78	0.25	46
Mid-Season	7-12	1464.54	370.85	48	1.07	0.43	48
Late-Season	13-18	1966.19	702.01	46	1.05	0.54	46

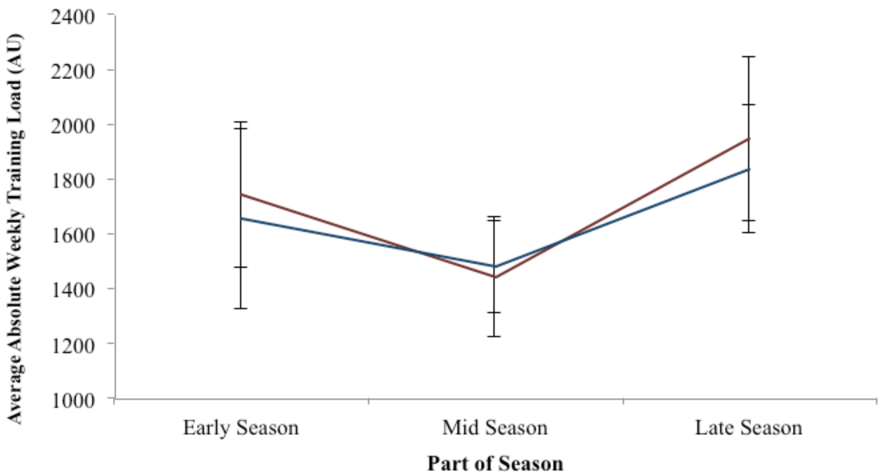

Figure 4.2. Part of season relative to the average weekly absolute internal training load, separated by movement quality group. The blue line represents the good movers (n=18, LESS score ≤ 4). The red line represents the poor movers (n=29, LESS score ≥ 5).

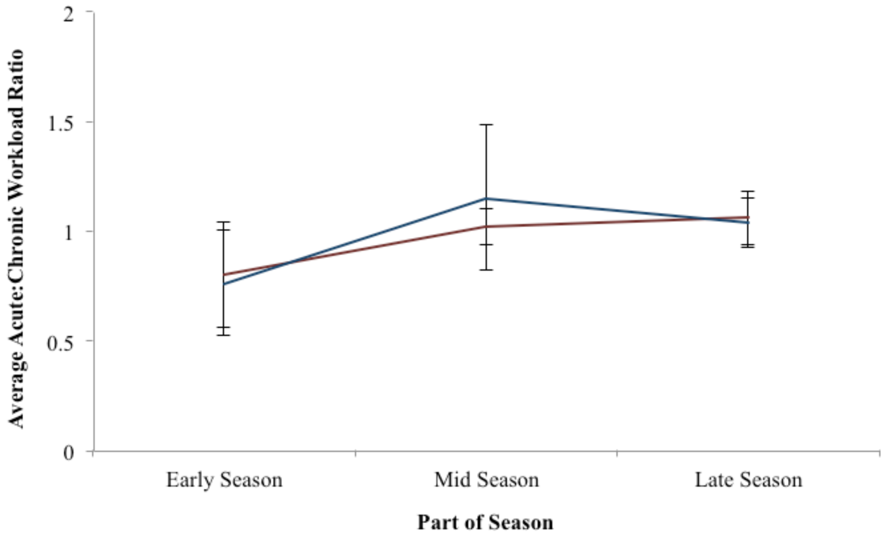

Figure 4.3. Part of season relative to the average acute:chronic workload ratio, separated by movement quality group. The blue line represents the good movers (n=16, LESS score ≤ 4). The red line represents the poor movers (n=30, LESS score ≥ 5).

Table 4.2. Descriptive Statistics of the Part of Seasons Separated by Movement Quality

	Average Weekly Absolute ITL				Average ACWR			
	Poor Movers		Good Movers		Poor Movers		Good Movers	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Early Season	1743.07	263.46	1652.01	326.22	0.80	0.24	0.76	0.24
Mid Season	1442.05	218.63	1480.26	165.91	1.02	0.08	1.15	0.33
Late Season	1947.16	297.59	1833.81	231.21	1.06	0.12	1.04	0.11

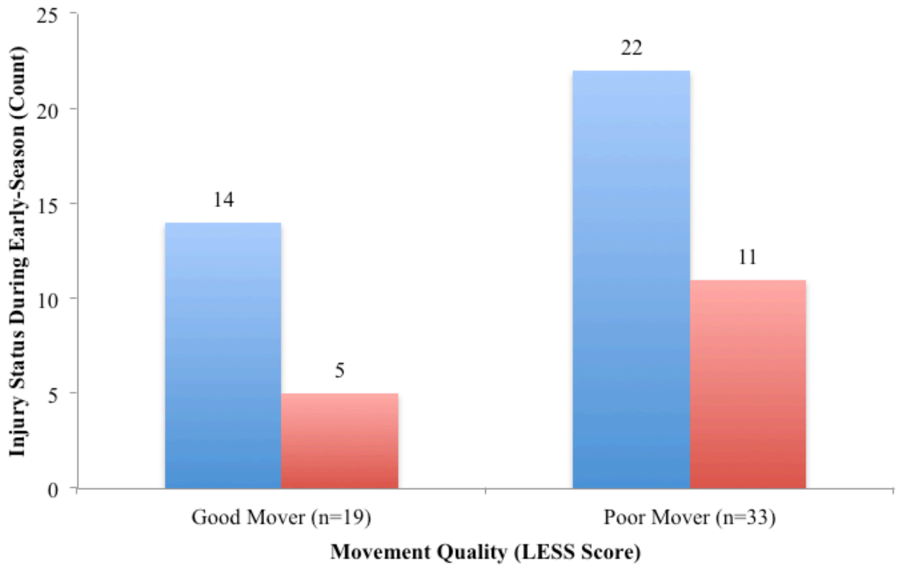

Figure 4.4. This bar graph displays the observed count for the Pearson's chi square test, comparing the injury status between movement quality groups. The blue bars represent participants whose did not sustain a lower extremity or low back injury during the first 6-weeks. The red bars represent participants who sustained at least one lower extremity or low back injury during the first 6-weeks. The counts for each are displayed above the bars.

Table 4.3. Lower Extremity (LE) and Low Back Injury Characteristics

	Acute	%	Overuse	%	Total	%
Region						
Ankle/Foot	10	9.1%	1	0.7%	11	10.0%
Hip/Groin	6	5.5%	1	0.7%	7	6.4%
Knee	1	0.9%	1	0.7%	2	1.8%
Lower Leg/Achilles	0	0.0%	3	2.0%	3	2.7%
Low Back/Pelvis	2	1.8%	3	2.0%	5	4.5%
Thigh	3	2.7%	1	0.7%	4	3.6%
Total	22	20.0%	10	9.1%	32	29.1%
Diagnosis						
	Acute	%	Overuse	%	Total	%
Sprain	11	10.0%	0	0.0%	11	10.0%
Strain	9	8.2%	3	2.7%	12	10.9%
Tendinopathy	0	0.0%	4	3.6%	4	3.6%
Bursitis	2	1.8%	0	0.0%	2	1.8%
Other	0	0.0%	3	2.7%	3	2.7%
Total	22	20.0%	10	9.1%	32	29.1%

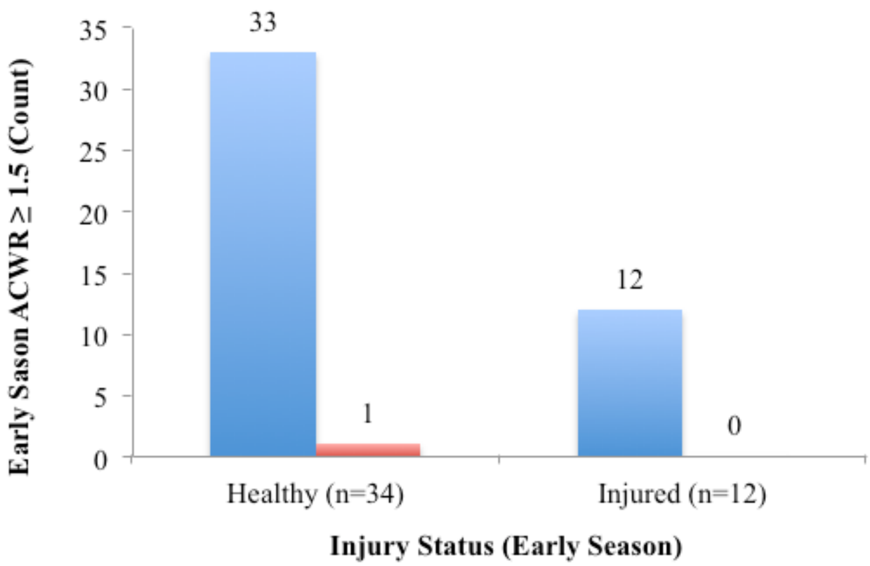

Figure 4.5. This bar graph displays the observed count for the Pearson's chi square test, comparing the average acute:chronic workload ratio (ACWR) between injury status during the early season. The blue bars represent participants whose average ACWR during the first 6-weeks were < 1.5. The red bars represent participants whose average ACWR during the first 6-weeks were ≥ 1.5. The counts for each are displayed above the bars.

CHAPTER V
DISCUSSION

The purpose of this investigation was to examine the associations among relative and absolute rates of internal training load (ITL), LE movement quality, and risk of injury in NCAA Division I male collegiate soccer athletes during two traditional seasons. Our results demonstrate significant differences in absolute internal training loads (ITL) between different times of season. However, we did not find an association between movement quality, ITL or injury risk.

Research Question 1

How do relative (ACWR) and absolute (total weekly sum) internal training loads change during an NCAA Division I men's collegiate soccer season?

Average weekly absolute ITL was shown to be significantly greater during both the early-season and late-season segments compared to mid-season. The late-season segment had the highest average weekly absolute ITL. This supports our hypothesis that training loads vary throughout a collegiate men's soccer season and be higher in the late-season segment, which encompasses preparation for postseason play and postseason tournaments. However, we did not predict higher loads in pre-season. There were no significant differences found between ACWR values during each part of the season. However, the largest values were observed during the postseason, which supports part of our hypothesis.

We began collecting ITL on the first day of pre-season summer training. Five weeks of ITL data are required to calculate an ACWR and examine the relative ratio from the most recent week to the previous month. NCAA soccer players are not required to report to school until just before team camp begins, meaning we were only able to generate an ACWR for the final two weeks of the early-season segment. This is a limitation of the current investigation because variations in an athlete's summer training could lead to variation in responses to the twice-daily training sessions that occur during the first two weeks of the early-season segment. This is particularly troublesome as the early-segment featured the highest injury rate with 50% of lower extremity and low-back injuries occurring during this segment. According to NCAA rules, Division I student-athletes in college soccer cannot be required to participate in any team activity in the summer prior to the start of their official season.[38] Thus, the current structure of NCAA collegiate soccer appears to limit the effectiveness of ACWR as a measure of training load during the early segment of the season. The ability to collect any ITL data prior to summer camp would depend on the desire of the individual players to voluntarily collect and report their own training load data throughout the summer.

The highest ACWRs (as denoted by the red line in Figure 4.1) were during Week 13 and 14. The greatest absolute ITL values were also recorded during this period of time. The increase in ACWR was largely influenced by the spike in absolute ITL during the same segment. In the two consecutive seasons studied, the last match of the regular season was played during Week 12, giving the team eight days until their conference tournament. Due to a loss in the first round of the conference tournament in both seasons, there was a larger break prior to the start of the NCAA tournament. During these two weeks (Weeks 14 and 15) the length of practices increased, contributing to the increase in absolute ITL and subsequently the ACWR relative to the final weeks of the regular season.

The majority of ITL and ACWR research has been performed on professional athletes[15]. In a study performed by Malone et al,[13] it was determined that professional soccer players who experienced a 1-week absolute load of ≥1500 to ≤ 2120 AU in the pre-season were at significantly higher risk of injury compared to those who experienced less than ≤1500 AU. The average weekly absolute training load for Week 1 in our sample was 2325 ± 331 AU, with 100% of the current sample experiencing loads greater than that described in Malone et al's study. One reason for such a drastic difference is the variance in season duration. Professional soccer seasons may last nine to eleven months, depending on a team's success, while NCAA seasons are < five months. Thus, early peak fitness may be a much higher priority to NCAA soccer coaches.

Match scheduling between professional and NCAA Division-I soccer also differs. In professional European soccer, competitive matches are played very frequently, with an average of three days recovery[91] due to participation in league and various tournament competitions.[92] In professional soccer, not all tournaments are high priority, which creates opportunities for a team's top 11 players to rest in lower priority games. For the current sample (see Table 5.1), the fewest days between matches (3.15 ± 1.27 days) occurred during the mid-season segment, while the late-season segment had the most days between matches (7.40 ± 3.37 days). We recognize that match scheduling influenced our absolute training loads. For example, less time between games in the mid-season segment likely led to shorter, less intense training sessions in an effort to maximize performance in games. In comparison, greater time between matches in the late-season segment likely resulted in longer and more intense practices. While speculative, this pattern does correspond with the observed patterns within the absolute training loads (Figure 4.1).

Match congestion (i.e. scheduling) has been the focus of several previous investigations.[92,93,94] For example, Dupont et al[92] found that 3-4 days between matches was enough to maintain physical performance, but did not protect against injuries. Moreira et al[94] noted that sRPE did not change during a match-congested schedule (i.e. a schedule with <1 day between matches) in youth soccer players. However, decreased hormone levels, such as testosterone, and performance were associated with accumulated fatigue during such a schedule. Thus, it appears that match scheduling can have an impact on a variety of factors related to athlete health and performance but additional, more comprehensive, research is needed to understand the connections among these factors.

This is the first investigation that has explored training loads in an NCAA field sport. While absolute training loads differed across the season, our investigation also identified multiple factors, such as movement quality, which should be considered in future investigations. Due to the context of many of these factors, it appears professional soccer training load data will not translate to NCAA student athletes playing men's soccer. Future studies should build on our initial results using larger sample sizes in an effort to determine meaningful absolute training load values during the pre-season as measures of ACWR will not be readily available due to current NCAA rules. Research is also needed to determine the effect of NCAA soccer scheduling, and coaching strategies related to between-match-practice intensities on ITL, performance and biomarkers of athlete health (e.g. hormone levels)

Research Question 2

Do NCAA Division I male collegiate soccer players with good versus poor movement quality exhibit varying relative (ACWR) and absolute (total weekly sum) internal training loads during their season?

There is no available research that has examined how movement quality influences training load throughout a traditional season. Our results illustrated that movement quality did not influence either absolute or relative ITL. We hypothesized that poor movers (LESS score ≥5) would have higher average absolute ITL compared to good movers (LESS scores ≤4), and that similar trends in the relative ITL (ACWR) would be present.

The small sample size associated with our study may have limited our ability to identify meaningful differences in movement quality between good and poor movers. Of the 47 participants analyzed, the majority were identified as poor movers (61.70%). In a study performed by Padua et al,[38] 64% of 827 athletes (age: 13.9 ± 1.8; 42% males, 58%

females), tested prior to the start of their season had a LESS score of ≤4, where 36% had a LESS score of ≥5. While this suggests that our sample may be representative of athlete movement quality, sex is known to influence performance and biomechanics.[6,31,32,41] Therefore, direct comparisons between the studies should be done with caution.

Though not shown to be significant, poor movers in our sample may have had larger changes in average weekly absolute ITL across the season segments (Figure 4.2). For example, from the early-season to mid-season segment, poor movers had a 17% decrease in their average weekly absolute TL compared to good-movers who only experienced a 10% decrease. Similarly, from the mid-season to late-season segment, poor movers experienced a 35% increase in average weekly absolute ITL compared to a 24% increase for good movers. In studies examining Australian Rules Football players, large week-to-week changes of >10% or cumulative week changes of ≥75% were found to be associated with increased risk of injury.[95,96] Given the preliminary nature of our investigation and the limitation – noted previously in this section – associated with ACWR, future research should explore relative change in absolute training load as a possible indicator of injury risk in NCAA athletes, particularly for poor movers. Similarly, future research is needed to explore the interaction between movement quality and training load on fitness declines throughout an entire season.

Research Question 3

Does the proportion of NCAA Division I male collegiate soccer players that incur an early-season low back or lower extremity injury differ significantly between those with good versus poor movement quality?

There was no association found between movement quality and injury status during the early season segment. Thus, we are not able to support our hypothesis that athletes who are defined as poor movers (LESS score ≥5) will have a higher risk of sustaining a low back or lower extremity injury compared to those athletes who are defined as good movers (LESS scores ≤4). While the majority of the injuries during the early season segment (68.75%) were sustained by poor movers, the proportion of injuries sustained between movement groups was not statistically significant (p=0.598). However, the higher number of injuries sustained by poor movers suggests that a cohort of poor movers should be potentially targeted to improve movement and decrease their injury risk.

The first two weeks of the early-season (Figure 4.1) segment represents a collegiate soccer preseason. The literature has shown that pre-season practices have a higher injury rate compared to the remainder of the season.[4] In our study, 50% of the observed injuries occurred during the early-season segment. Various reasons for this increased injury rate have been presented, such as lack of conditioning during the time prior, limited time between practices that decreases potential for recovery, and increased length and intensity of the preseason practices compared to in-season practices.[4] Table

5.2 presents time (minutes) and sRPE for each part of the season. For both minutes and sRPE, the early-season segment's values were >20% higher than the mid-season segment. Our findings are consistent with the existing literature on Australian rules football and professional soccer players.[94,96,97] Further, our data indicate that the minutes and sRPE from Week 1 and 2 represented 43-44% of all minutes and SRPE experienced during the early-season segment, which supports the hypothesis that workloads during the pre-season are significantly higher compared to the regular season.

Padua et al found that elite level youth soccer athletes who had LESS score of ≥5 had a greater risk (1.2% increase) of sustaining an ACL injury compared to those with a LESS score <5.[38] Using the Functional Movement Screen (FMS) system, athletes who score ≤ 14 (i.e. poor movers) were also at an increased risk of injury.[98] In comparison, Everard et al[99] found no association between composite FMS score ≤14 and injury in male military academy cadets. Poor movement assessed via the LESS (i.e. score >5) and FMS scores of 1 were associated with an increased injury risk. When utilizing the LESS and other movement assessments, clinicians need to account for confounding factors such as sex,[40,41] fatigue,[100] and previous injury history.[38] For example, Gokerler et al[100] demonstrated that fatigue immediately impairs LESS performance. Fatigue developed over the course of one game,[101] as well as over the course of a season,[102] has been connected to decreases in athletic performance, and increased in injury risk.[24] However, the impact of cumulative fatigue and/or in season training on movement quality remains unknown.

Research Question 4

Does the proportion of NCAA Division I male collegiate soccer players that incur an early-season low back or lower extremity injury differ significantly between those with and without a high (>1.5) relative internal training loads (ACWR)?

In the early-season segment, one healthy player (out of 34) experienced an ACWR that was ≥1.5. In comparison, zero injured players (out of 12). This was not found to be statistically significantly (p=0.548) (Figure 4.5). As stated previously, a large limitation of the ACWR in NCAA soccer student athletes is the need for five weeks of continuous ITL data in order to examine the relative change of the acute load (one week) to the chronic load (four weeks)[103]. This limitation greatly diminished our ability to identify spikes in ACWR during the early-season segment, as the ACWR was only calculable for the final two weeks of this segment.

Blanch et al[104] noted that an ACWR spike ≥1.5 increased an athlete's risk for injury in cricket, rugby league and Australian rules football. Malone et al[13] found that soccer players who did poor on pre-season fitness testing, experienced greater injury risk when they experienced an ACWR of ≥1.25. The average ACWR for the early-season segment in our sample was 0.78 ± 0.25. However, this should be interpreted with caution as the ACWR was not calculated during the first four weeks of the early season segment (as described above). The potentially largest spike in TL for college soccer athletes is during Week 1 and 2 of their season, when they begin twice-daily training sessions. Future research is needed to identify a measure capable of quantifying injury risk in the early season within NCAA athletes given their unique constraints on reported training load data prior to their pre-season camp.

Other Factors to Consider

Mental Fatigue

Different from professional athletes, collegiate players spend a majority of their time outside of athletics. During a traditional season in Division-I college sports, the NCAA limits student-athletes to a maximum of four hours per day and 20 hours per week.[105] However, it is important to note that daily and weekly hour limitations do not apply during preseason practice.[105] This is in addition to being enrolled in a full-time program, which can be between 12-18 credit hours.[105] In comparison, an average professional soccer player spends 6-24 hours per week completing a variety of training sessions (i.e. standard training, weights, etc) with the remaining time being personal. The additional constraints on college athletes likely play a role in their overall performance and have been linked to increased fatigue, specifically mental fatigue.[106]

Mental fatigue has been documented in the literature as a cause for decreased sporting performance.[106] In soccer specifically, mental fatigue can lead to impairments in performance in soccer-specific running, passing, and shooting.[107] During the early-season, athletes begin classes and they have to adapt to the new loads placed on them both physically with soccer, and mentally in the classroom. During the mid-season segment, they are no large changes in classroom requirements; however, it is during the last few weeks of the late-season segment that NCAA soccer student-athletes are asked to both compete in post-season competitions, as well as complete finals exams. The mental fatigue developed during the start of school, as well as during the final weeks may be a confounding factor in the reasons for higher ITL during the early-season and late-season segments. Player fatigue due to mental activity was not directly examined in this thesis project, and should be considered in future investigations.

Other Analysis Options

There is some evidence in the literature that supports using ACWR has a means of monitoring athletes for injuries.[14,17,19–21] However, caution needs to be considered when utilizing ACWR to represent TL "errors", as some of the changes in load are due to uncontrollable variables, such as the demands of competition.[108] Changes in ACWR do not directly cause an injury; rather, they increase an athlete's risk of injury by exposing the athlete to potential situations, and causing change in other risk factors, such as fitness and fatigue.[109,110]

Current means of calculating ACWR use the idea of rolling averages, where the average of one week is compare to the average of the month prior. Rolling averages do not account for tissue conditioning, and overlook variations in a set period of time, obscuring the true picture of a workload throughout a season.[109,111] Other researchers have hypothesized using a non-linear TL model, or an exponentially weight moving average (EWMA), in substitution for the current method.[109] According to research by Dr. Menaspà's, the traditional means of calculating an ACWR fails to explain the declining nature of fitness, and effects of fatigue with time.[109,111] At this moment, it is unknown which method of calculating ACWR is more sensitive, or in combination with movement quality, work better to identify injury risk. However, future research should look to establish their comparative effectiveness.[110]

Summary

Our results demonstrate significant differences in absolute internal training loads (ITL) amongst different times of season. In addition, we did not find a statistically significant association between movement quality, ITL and injury risk. However, when examining the average training loads in early season, athletes who were described as poor movers had a higher average weekly absolute ITL (1743.07 ± 263.46 AU) compared to those athletes who were described as good movers (1652.01 ± 326.22 AU). In addition, poor movers had overall more injuries (40% more) throughout the season compared to good movers (Figure 5.1).

Even with a majority of the team being included in the poor mover group (63.46%), movement quality association with training loads and injury risk presents with trends that warrant further research with larger sample sizes. While there is value in movement quality as a screening tool for injury risk, it only encompasses one aspect of the injury etiology model described by Windt and Gabbett.[24] In training load research, there is an increase needs to determine the mechanisms in changes in ITL might cause injury, and what intrinsic factors cause athletes to be more robust or more susceptible to injury.[110] Movement quality has yet to be ruled out as a factor that mediates or moderates the relationship between TL and injury, or whether or not it is the reason WL changes or what causes athletes to get hurt at certain TL.[24,110]

Table 5.1. Average Days between Competition - Combined Season Averages

	n of games	Mean	SD	Maximum	Minimum
Early-Season	9	3.38	1.96	8	1
Mid-Season	10	3.15	1.27	6	2
Late-Season	5	7.40	3.37	13	5

Table 5.2. Total Team Average Sum of sRPE and Time for the Part of Each Season

	sRPE (AU)			Time (Minutes)		
	Mean	SD	% Change	Mean	SD	% Change
Early Season	147.67	25.24	-	2643.24	395.14	-
Mid Season	120.21	16.11	18.60%	2048.60	286.22	22%
Late Season	125.91	19.15	-4.75%	2624.20	368.99	-28%

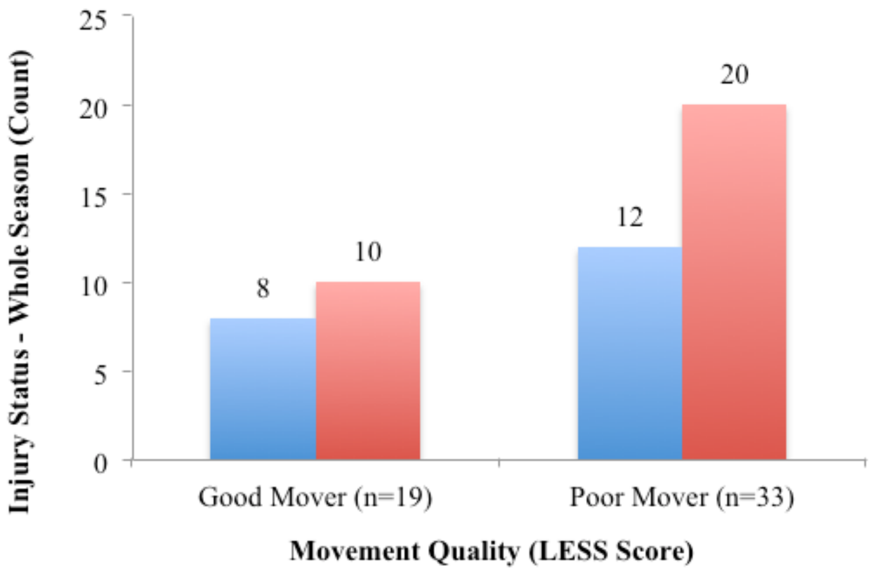

Figure 5.1. This bar graph displays the observed count comparing the injury status between movement quality groups for both seasons combined. The blue bars represent participants whose did not sustain a lower extremity or low back injury. The red bars represent participants who sustained at least one lower extremity or low back injury. The counts for each are displayed above the bars.

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