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A Prediction Model for Acute Core and Lower Extremity Injuries in Division 1 Collegiate Football Players

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A Prediction Model for Acute Core and Lower Extremity Injuries in Division 1 Collegiate Football Players

A thesis submitted in partial fulfillment
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Master of Science in Athletic Training

by

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This thesis is approved for recommendation to the Graduate Council.

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Abstract

Context: Various intrinsic factors such as high exposure, poor endurance of core muscles, previous injury, strength deficits, suboptimal neurocognitive function, and orthopedic abnormalities have been found as predictors for sprains and strains among collegiate football players. ***Objective****:* Assess the applicability of pre-participation assessments as predictors of core or lower extremity injury. ***Design****:* Cohort Study. ***Setting****:* National Collegiate Athletic Association Division I football program. ***Patients or Other Participants****:* Athletes who underwent mandatory pre-participation examinations before preseason football training over two consecutive seasons (n=225). ***Main Outcome Measure(s):*** Associations between preseason protocols and injury incidence for core and lower extremity injuries were established for 225 players using three different injury definitions; all injuries reported (ALL), limited participation (LP), and removed (OUT). Receiver operating characteristic analysis was used to establish cut-points that classified cases as high-risk or low-risk for injury incidence. Logistic regression and Cox regression analyses were used to identify a multivariable prediction model for injury. ***Results****:* A 4-factor model (FM) for ALL identified ≥2 Positive Factors for differentiating between injured and uninjured athletes (*P*<.001, OR=3.21; 90% CI 1.98, 5.20 , Sens=77.3%, Spec=48.5%). A 3-FM for LP identified ≥1 Positive Factors to be the criteria (*P*<.004, OR=2.41; 90% CI 1.41, 4.10, Sens=82.8%, Spec=33.3%). A 3-FM identified ≥2 Positive Factors for OUT to be the criteria (*P*<.012, OR=2.25; 90% CI 1.27, 4.00, Sens=75.4%, Spec=42.3%). A 4-FM identified =4 Factors to be the standard for injury in the previous season (*P*<.001, OR=8.61; 90% CI 4.00, 18.53, Sens=58.5%, Spec= 85.9%). A 4-FM identified ≥3 Factors for subsequent injuries during both years (*P*<.011, OR=8.40; 90% CI 2.00, 35.70, Sens=44.4%, Spec=91.3%). ***Conclusions****:* Injury definition appears to be important for identifying risk factors for football injuries. Additionally, there are modifiable risk factors that can be determined from previous season injury and for athletes who are injured in consecutive years.

Key Words: injury prediction, injury prevention, injury risk

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Dedication

I would like to dedicate this project to every athlete that has ever been injured and has repeatedly asked the question “Why me?”. While at the time it seemed unfair and like everything, including your dreams, was falling apart before your eyes, it is important to remember that with every set back there is learning and a growing passion for what you do. While at the time you couldn’t seem to think of anything else, each rough part in your life made you stronger, more dedicated, resilient, and determined.

If I had never been injured during my career I would have never had a growing interest in what predisposes an athlete to injury and if an injury could be predicted before it even happened. It is because of my past that I have this passion for trying to “change the future”. It is because of this that I dedicate this project to you.

Table of Contents

I. Introduction 1

- A. Statement of the Problem 3
- B. Hypotheses 4
- C. Assumptions 6
- D. Limitations 6
- E. Delimitations 7
- F. Significance of the Study 7
- G. References 8

II. Literature Review 10

- A. Format of Current Prediction Models 10
- B. Competition Level, Game Exposure, and Playing Position 11
- C. Previous Injury 13
- D. Body Mass Index and Mass Moment of Inertia 14
- E. Neurocognitive Function 17
- F. Current Psychological State 19
- G. Muscle and Joint Flexibility 21
- H. Core Stability and Strength 23
- I. Bilateral Strength and Power Imbalances 25
- J. Functional Movement Screen^{TM} 28
- K. Nutritional Deficiencies and Insufficiencies 30
  - Vitamin D 30
  - Iron 32
- L. References 35

III. Methods 42

- A. Participants 42
- B. Data Collecting Location, Ethics, Consent, and History 42
- C. Variables 43
- D. Testing Protocol 43
  - Injury Definition and Documentation 43
  - Experience Level 44

Game Exposure 45

Previous Injury History 45

Body Mass Index and Mass Moment of Inertia 46

Neurocognitive Function.. 47

Current Psychological State 48

Muscle and Joint Flexibility.. 51

Core Stability and Strength 52

Bilateral Strength and Power Imbalances 53

Functional Movement Screening 55

Nutritional Status and Deficiencies... 56

E. Data Analysis 58

F. References 60

IV. Manuscript 65

A. Abstract 66

B. Introduction 67

C. Methods.. 69

D. Results 73

E. Discussion 80

F. References 89

G. Figures and Tables 92

V. Discussion and Conclusion.. 103

VI. Appendix 105

I. Introduction

It has been said that “injury is just part of the game” [1] and that injury is simply an inevitable consequence of sport participation that should be expected. Every year seven million adolescents, ages 14 to 18, take part in high school athletics.[2] Additionally, there are currently 420,000 college athletes in the NCAA.[3] While athletics promote good health, they can also be dangerous in form of accidents and injuries. These injuries can result in the failure to achieve one’s goals, increased medical treatment and costs, absence from school and work, permanent psychological distress, and termination of one’s athletic career.[4]

Various studies have surveyed the incidence of athletic injuries and have defined the scope of injury amongst athletes. Unfortunately, reduction of injury burden can’t be done if nothing is done to prevent injury.[5-7] Serious injuries involving structures such as the anterior cruciate ligament are a growing concern in sports that include high rates of contact paired with pivoting and cutting.[8] Other injuries to the lower extremities, hamstring strains and ankle sprains, are also becoming more prevalent.[5,9] Agel & Schisel (2013) found that collegiate preseason practice injury rates were 6.3 per 1000 game exposures (95% CI, 6.3-6.3) with injury rates climbing with increased level of competition; Division I at 6.8 compared to Division 2 at 6.0 per 1000 game exposures. Turbeville, Cowan, Owen, Asal, & Anderson (2003) found that increased injury rates even extend into high school sports. It was found that in 132 high school football players who sustained various injuries during a single football season, 54% of injuries were sprains and strains, 17% were contusions, and 11% fractures.

While there are many definitions of a “sports injury”, it is widely accepted that a sport injury has been sustained when an athlete is not able to fully participate in sport warranting an evaluation and requires medical treatment until full participation can be resumed.[1] Additionally, the NCAA states that an injury has been sustained when an athlete is unable to participate in sport and must completely miss at least one practice or game.[3] It should be noted that many athletes may approach the medical staff with a believed injury that warrants an evaluation, but does not result in missed or modified time in practice. Regardless it is accepted that sport injuries are a significant public health issue and that there is a strong need for preventative approaches.[12]

Today, most research focuses on the incidence and mechanism of injury. Some research has even gone as far as to use this information to prevent certain injuries.[7] The most commonly cited model for sports injury prevention was suggested by Van Mechelen in 1992. Mechelen suggested that prediction models should seek to operate in a sequence by first identifying the incidence of injury, identifying the common factors and mechanisms associated with the injury, introducing measures likely to reduce future risk, and finally reevaluating these measures and modifying as necessary by returning to the first step of the cycle. It can be argued that further research needs to be conducted based on such data. In addition, professionals should be able to target susceptible athletes before the first injury occurs and implement preventative measures prior to activity.

Another widely accepted theory proposed by Meeuwisse, Tyreman, Hagel, & Emery in 2007, suggests that each individual has their own particular set of factors that predispose them to injury that are dynamic and can change frequently. These factors can be separated into intrinsic and extrinsic risk factors.[13] Intrinsic risk factors can be defined as predisposing factors that act from within the athlete; nutritional status, neuromuscular control, age, the individual’s anatomy, sociological distress, strength, and previous injury. Extrinsic risk factors are factors that act on the athlete from the outside to amplify the intrinsic factors that cause injury; playing surface, weather, practice versus game, and playing equipment.[1,5,6,13] The combination of these factors completes the chain of events and causes the athlete to enter the cycle of sports injury.[13]

In the literature, there are various prediction studies that have tried to determine which athletes are more predisposed to injury than others. Some studies focus on the prediction for a certain injury, such as ankle sprain occurrence in high school football athletes[9], while others aim to predict the occurrence of any acute upper and lower body injury in sport. Wilkerson, Giles & Seibel in 2012 took various preseason measurements in college Division 1 football athletes and documented game exposure as well as injury incidence during the football season. At the end of the season, preseason screening data was analyzed and a four criteria prediction model was created that could be utilized before season to determine the risk of each athlete to sustain an injury during the season.

While many factors may cause injury, not all factors can be manipulated. For instance, medical professionals and coaches cannot change the playing surface the athletes are competing on, control the weather, or dictate the opponent’s skill set. Conversely, intrinsic factors such as neuromuscular control, could be altered due to the fact that fatigue could interact with another risk factor to create an injury that otherwise may not have happened.[13] Therefore, prevention should be focused on the factors that can be altered, intrinsic factors.[7,13]

Statement of the Problem

Today, research is done to assess the incidence of injury rather than to determine if athletes are susceptible to injury.[6,7,12] In reality there are many protocols that can be administered in a preseason or mid-season evaluation that may help professionals determine if an athlete is at risk. Unfortunately, time, resources offered, and involved member compliance often hinders the reliability and validity of evaluations.[2,13] Professionals need to identify tests that have the highest validity to identify athletes at risk for injury so that the medical professional's time can be used efficiently help ensure the longevity of an organization's athletes.[2]

The purpose of this study was to assess the value of different variables that have been shown to be potential risk factors for core and lower extremity sprains and strains in NCAA Division 1 collegiate football players. A secondary purpose was to identify the strongest set of predictors for a cohort of athletes to categorize athletes as either high or low risk for injury occurrence which could be further used as a way to predict athletes who may be susceptible to injury over the course of a season. A tertiary purpose was to assess whether definition of injury occurrence changes the set of potential predictive factors and thus the risk of injury occurrence. Lastly, this study will assess whether previous season injury occurrence is indicative of injured status during the next competitive season and what potential risk factors that these athletes have in common. Data will include psychological profile, medical history profile, strength and conditioning performance measures, event exposure time, and orthopedic assessment completed prior to the season to determine a prediction model for athletic injury that can potentially be utilized among similar athletic cohorts to determine if an athlete is susceptible to injury in an easy and reliable fashion.

Hypotheses

The hypotheses for the research study presented above are as follows:

1. An increase in years of experience will significantly predict a lower body extremity injury.

2. Occurrence of lower body extremity injuries will be significantly predicted by an increase game exposure.
3. A previous history of lower body extremity injuries will significantly predict lower body injuries.
4. Suboptimal neurocognitive abilities will significantly predict a lower body injury during the football season
5. Suboptimal strength of the lower body and core will predict an athlete's increased susceptibility to sustain a lower extremity injury.
6. The rate of lower body extremity injuries will not be significantly predicted with increased body mass in terms of body mass index, BMI.
7. Abnormalities in psychological distress measures will not significantly predict the susceptibility for an athlete to sustain a lower body injury
8. Nutritional deficits measured with preseason blood work will not be indicative of sustaining a lower extremity injury during the season.
9. Suboptimal Functional Movement Screen^{TM} scores will not significantly predict the occurrence of a lower extremity injury.
10. There will be a strong correlation between game exposures, history of lower body extremity injuries, deficits in core and lower body bilateral strength, and suboptimal neurocognitive abilities in terms of predicting a lower body extremity injury.
11. Injury occurrence during the first year of data collection will not influence the outcomes of the associated model the second year.
12. Models created for the first and second year of collection will not be statistically different.

Assumptions

1. Each athlete included was healthy, not currently injured or recovering from a previous injury, at the moment of data collections.
2. Each athlete has put forward their greatest effort during testing.
3. During screening questionnaires, each athlete answered honestly.
4. During preseason evaluations, all identified player data was be measured by a licensed professional.
5. When an injury is sustained that the athlete sought out medical attention for evaluation and treatment.
6. When an injury is sustained that medical professionals accurately and immediately documented the injury and treatment that follows.
7. All injuries sustained will have occurred during sport; practice or competition.

Limitations

1. The motivation of each athlete put forward may not be their greatest effort during testing. In order to encourage motivation, athletes were encouraged and supported during each testing exercise.
2. That each athlete has answered all questionnaires completely and honestly. In order to ensure the best possible compliance, athletes were made aware of the knowledge that could be gained from this study and encouraged to be as honest as possible.
3. There is no ability to predict game exposure before the season. Game exposure for each athlete was documented throughout the season.

4. That when an injury is sustained the athlete may not have sought out medical attention for evaluation and treatment. Athletes were encouraged to seek medical attention if there is any question of injury.
5. Cut points for various tests for creation of a prediction model have been created for this cohort of athletes only.
6. Individual players may have had a change in risk factor profile in a short period of time.
7. There are various method to assess similar components in this testing protocol that may achieve different outcomes.

Delimitations

This study was limited to members of a single male, NCAA Division I football program that should be able to apply to all Division I collegiate football teams in the United States in terms of predicting lower extremity injuries during the course of a football season.

Significance of the Study

The significance of this study is to further develop the current knowledge in regards to occurrence, prediction, and prevention of sport injuries in competitive athletic programs. This study will examine different variables that may be indicative of injury and will use results to create a prediction model that will further aid the injury prevention realm in athletics. With this model, medical professionals will be able to examine athletes before each season and determine their susceptibility for an injury before it occurs. If an injury can be predicted before its occurrence then specific prevention protocols can be incorporated into each athlete’s training regimen to ensure high performance levels and a reduction in injury.

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II. Literature Review

Injury prevention is an important aspect of Athletic Training. Today, research focuses on the incidence of injury and how the injury occurred, but identifying the predisposing factors that people have in common is often forgotten.[6,7,12] Identifying the risk of sustaining an injury and further preventing injury is very complex because of the wide array of factors that may make an athlete susceptible.

The most commonly cited prediction theories by Van Mechelen in 1992 and Meeuwisse et al. in 2007 suggest that each individual has their own particular set of factors that predispose them to an injury. Further, professionals must realize that each individual is not stagnant, but rather they are a dynamic entity that changes with time. Risk factors that were once apparent at a point in time may not be apparent in the future, making prediction of injuries very difficult.

In addition, it is the combination of internal and external risk factors that interact at the inopportune moment that cause an injury.[1,5,6,13] It has been suggested that professionals should aim to change an athlete's intrinsic factors because there is no way to guarantee control over external factors that may occur each day. While there are many factors that may cause an injury, it is important to realize that not all factors can be manipulated, such as age and gender, which will remain specific to the athlete.[13]

Format of Current Prediction Models

Most recent prediction models have acknowledged that before an assessment of causation can be made, the effect of a given variable must be examined in all individuals exposed to the possibility of injury.[15] While some injuries are unavoidable, many others may be identified through proper screening techniques.[14] To this end, it is apparent that the most current prediction models assess variables through cohort studies.

In cohort studies, potential characteristics that may predispose an athlete to injury should be evaluated before the risk of injury becomes amplified due to practice and competition. After the relevant time period has lapsed the risk factors are then analyzed separately and collectively for predictive value with the incidence of injury [6,14] This allows professionals to separate and combine each risk to determine if there is a relationship that can cause an injury that could have easily been avoided if the risk factor had been identified earlier. It has been suggested that in order to find significance in a cohort study approach that researchers observe and estimate 20 to 50 injury cases with at least 200 participants.[6]

From collected data, cut points can be created for a particular cohort. The biggest limitation to these prediction models is that there are variations in ways that variables can be assessed and that there is cohort variability from one year to the next.[14] In terms of an athletic cohort, teams will change each year with a change in training techniques and staff employment. Further the techniques for assessing the same component of the athlete's make up may also vary.[16] With cohort variability and means of assessing different characteristics, prediction models will be susceptible to change but it must be realized that with each prediction model created, there will be commonalities in the risk factors that are found to be significant. It is important that professionals continue to create prediction models so that common variables can be assessed and knowledge in regards to predicting injuries can be increased.

Competition Level, Game Exposure, and Playing Position

It has been argued that an increase in competition level and experience is positively associated with an increase in the occurrence of injury.[11] As athletes increase in age, they often move up in playing divisions exposing them to other athletes of various ages who may have had more experience and training than others have had. The National Football League has previously reported that injuries occurring on professional teams may also be associated with the "make the team mentality".[17] This same mentality holds true for players who are in transition from lower levels of competition to higher levels; middle school to high school, high school to college, and college to professional.

With this lack of experience and exposure to intense playing conditions, athletes may be at higher risk for injury than another player who has had more experience at a particular competition level.[18] Current predictions models have aided in supporting the claim that an increase game exposure via experience and potential starter status has been linked with increased risk for injury.[14]

Injuries, whether traumatic or overuse in nature, are a common impediment in sport. Preseason practices are often responsible for a share of injuries but most athletes become most vulnerable when transitioning from preseason to competition season because teams are often not mentally or physically prepared for the intensity that is demanded of them. This theory also holds true for athletes who must transition from regular season to championship season mentality which continues to place high demands socially, physically, and mentally on athletic teams.[10,19]

In competition, players are likely to be playing at a greater intensity and speed which may increase the risk of injury.[7] It has been found that the relative risk of injury can be up to ten times higher in games compared to practices and those athletes who frequently are subjected to high intensity levels are more likely to sustain an injury than those who do not play regularly in games and are not of starter status. Further, athletes who play positions that are subject to high forces and work levels, such as linemen in football, have been found to be two times more likely to sustain an acute lower extremity injury than their fellow first string teammates of different positions.[11] Increased experience and playing time may increase the risk of injury due to repetitive and cumulative trauma from continuous contact, running, and cutting while fatigued from training and other competitions.

It was found by Turbeville et al. in 2003 that an increase in football experience was associated with a 40% to 60% increase in injury risk for every one year increase in experience. It was also suggested that athletes who have longer playing time during games than their teammates also have a greater opportunity to be injured. As athletes become older and more aggressive they are likely to experience increased playing time compared to younger, less experienced players.[5] These athletes who are subjected to increased playing times and are in transition from one competition level to the next should be closely monitored to ensure their health and success.

Previous Injury

In the literature, many professionals and researchers have supported the claim that previous injuries may be associated with the occurrence of another injury.[14,15,20] At collegiate and professional levels more attention is being placed on evaluating and treating the entire kinetic chain after an injury due to the fact that there can be residual dysfunctions in the athlete's chain of movement.[19] If an injured athlete does not receive adequate rehabilitation, the injury may not heal completely and the athlete may develop other intrinsic risk factors and kinetic chain dysfunctions that were not present before.

In a study done by Tyler, McHugh, Mirabella, Mullaney, & Nicholas in 2006 on ankle injury incidence of high school football players, it was found that 22% of the athletes with a history previous ankle sprains sustained another sprain during the current season. It was further recognized that these athletes were six times more likely to be injured than players who had not sustained a previous ankle injury. Similarly, another study on professional soccer players found that players who had a history of previous strains to the quadriceps and hamstrings were also more likely to sustain another strain to these muscle groups at another point during their athletic careers.[21]

One current prospective study by Fousekis et al. in 2012 identified intrinsic risk factors for ankle sprains in professional soccer players and found that 49% of the players who sustained an injury had a previous history of ankle sprains. This study also found that these athletes may have asymmetries in neuromuscular coordination, strength, and reaction time as well as deficits in other components required for adequate performance. Signs of a lack of full recovery from a previous injury, in terms of muscle imbalances and weakness as well as a decrease in joint function, can exponentially increase the risk for a subsequent injury.[20] It can then be suggested that athletic performance may also be decreased in these individuals. This was supported by Nadler et al. in 2002 who found that college freshman with a previous lower extremity injury were significantly slower on the shuttle run compared to freshman without a previous injury and were more likely to sustain an injury than athletes from any other year.

Body Mass Index and Mass Moment of Inertia

Body Mass Index (BMI) is intended to provide an indication of how overweight a person is by adjusting body mass for height.[9] It has been suggested that with the increase in BMI there is an increase in the risk for musculoskeletal injury, either directly as a result of greater joint loading or indirectly through its association with the possibility of poor physical conditioning.[22] High BMIs may be related to the athlete's ability to effectively and rapidly change momentum.

During physical activity a greater force is required to change the movement of a heavier person. High BMI values may cause injuries, such as sprains and strains, when the athlete attempts to decelerate or change direction quickly.[9] When a joint, such as the ankle joint, is not stable enough to transfer the ground reaction forces that allows for an athlete to effectively change their momentum, an injury may result that can cause the athlete to sit out for an extended period of time. Some athletic events require athletes to maintain a higher body weight than the average person. This holds true when comparing the higher BMI values of football linemen and tight ends compared to the lower values for receivers and quarterbacks. While certain sports deem a certain physique necessary for performance, it is important for professionals to realize that the incidence for injury in these players may be similar. Tyler et al. in 2006 found that injury incidence for quarterbacks, running backs, and linebackers was 1.1 per 1000 playing hours and 1.38 per 1000 playing hours for linemen and tight ends.

In a study done by Gomez et al. in 1998 on 234 football athletes, it was found that athletes with a BMI of less than 20 had an injury incidence of 1.08 injuries per 1000 playing hours while athletes with a BMI greater than 20 had an injury incidence of 4.10 injuries per 1000 playing hours. It was concluded that player BMI was able to predict a lower extremity injury 78% of the time. These findings were supported by another study that states that athletes who were categorized as overweight had 3.9 times greater chance of sustaining an ankle sprain then those who were not overweight. It was also found that athletes who had a high BMI and a previous ankle injury had an injury incidence of 5.58 per 1000 playing hours.[9]

High BMI values don't always correctly identify if an athlete is overweight, and is not often valid for the athletic population in which high BMI values may be caused by increased levels of muscle mass.[9] On the other hand, in the realm of athletics, where time is limited, BMI may be the quickest and the only resource available to professionals when assessing an athlete's body composition.

A current prediction model by Fousekis et al., 2012, supported the claim that a high BMI is a risk factor for lower extremity injury. In this study, it was found that athletes with a BMI over 23.1 presented an eight times greater compared to those with a lower BMI. The model the authors proposed that included BMI, increased body weight, and strength asymmetries classified 89% of ankle injuries correctly.

An older concept that has been utilized by Milgrom et al. in 1991 stated that rather than identifying if an athlete's BMI is a predictor of injury, that professionals observe the height of an athlete's mass moment of inertia instead (MMOI). MMOI is located at a person's center of gravity and can be different for each person depending on the shape of the body and its anatomical makeup. MMOI is calculated through the sum of the moments of inertia of the masses that make up the whole body and is calculated by Mass (kg)*Height (m^2). It has been suggested that the larger and higher an individual's center of mass is, the more likely the individual is to sustaining a lower extremity injury since they are more unstable than an athlete that has a lower or smaller center of mass.

Researchers often look at an athlete's BMI rather than an athlete's MMOI because it is more widely accepted as the norm. A recent study by Wilkerson et al. (2015) found that a high MMOI was associated with an increased risk of lower extremity injury with an odds ratio of 2.08 and a relative risk ratio of 1.48. Though this variable was not significant enough to be included in the prediction model, it should not be ignored that MMOI may play a larger part in an athlete's risk for lower extremity injury.

Previously in 1991, Milgrom et al. found that greater mass moment of inertia and previous injury were strongly correlated with the incidence of ankle sprains in military recruits. Researchers concluded that during the stance phase of walking, the body rotates around the ankle joint in a complex way. While rotations about the frontal plane are easily controlled by the body's anatomical make up and strong dorsiflexors and plantarflexors, rotations about the transverse planes are not so easily controlled by the weaker inverters and everters of the ankle joint. For this reason, athletes who are fatigued have poor neuromuscular reaction times, or who possess weak tendons and muscles from previous injury are more at risk for injuries than other athletes. When the athlete's center of mass is carried higher above the ground, it becomes harder for the body to protect itself and often sprains and strains occur.

Neurocognitive Function

Neuromuscular control is influenced by sensory information from proprioceptive, kinesthetic, visual, and vestibular sources, as well as from cortical and spinal motor commands.[25] During sport it is imperative that these sources perform efficiently and correctly in order to ensure the safety of the athlete. Maintaining dynamic control during complicated, high velocity movements that are characteristic in athletics is contingent on both correct muscle activation and reflex driven contractions. Deficiencies in reaction time, processing speed, visual memory, and verbal memory may indicate diminished ability of an athlete to maintain neuromuscular control and may predispose the athlete to an injury.[27]

It is becoming more common for professionals to evaluate their athlete's processing speed, working memory, attention, and concentration through the ImPACT test since it has been shown to be a reliable method for examining neurocognitive performance.[28,29] This test is often administered before each season and is now used in most concussion protocols to evaluate the athlete's current neurocognitive status. Decreased reaction times, processing speed, or visual and spatial disorientation values measured by this assessment may expose the athlete to injury due to a lack of neuromuscular control and awareness to maintain stability and to consciously make safe decisions.[27]

While a new concept, some recent studies have looked at the relationship between neurocognitive abilities and injury occurrence. Swanik et al. in 2007 examined athletes who had sustained an anterior cruciate ligament injury and their corresponding neurocognitive performance against athletes who had no history of previous injury. Results found that there was a difference in all four aspects of the ImPACT between these two groups. Athletes with previous ACL injuries had slower reaction times, slower processing speeds, and lower visual and verbal memory scores. It is possible that the athletes who had sustained ACL injuries may have had these deficits in neurocognitive performance prior to injury, which may have aided in the occurrence of injury. Further, Wilkerson et al. in 2012 found that football players with a suboptimal reaction time of less than .545 seconds had an increased risk for a lower extremity injury during the season by over 2 times.

There is an extreme demand for simultaneous awareness as well as rapid and efficient execution of complex motor patterns in athletics.[31] It is possible that mild deficits in reaction time and processing speed could make certain athletes more likely to make judgment errors or exhibit loss of coordination during competition. Further, athletes with decreased visual skills may have difficulty interpreting and negotiating conflicting information. This disorientation can ultimately disrupt the execution of motor activity, alter muscle activity, and diminish performance capabilities.[27] These athletes have a greater possibility of suffering from a lower extremity injury that could potentially hinder their future in athletics.

Current Psychological State

Playing sports as well as maintaining a healthy daily life can be very stressful on a person's psychological state of mind. Life stressors occur every day forcing athletes to deal with physical stresses as well as psychosocial stress that many professionals fail to realize during the athlete's career.[32] One of the earliest significant studies done on psychological stress by Bieliauskas in 1982 suggested that stress can be defined as any disruption or change in a person's mental, emotional, or physical wellbeing that can be caused by an external stimulus that is either physical or psychological in nature. It is possible that athletes with high amounts of daily stressors, certain personality characteristics, and poor coping resources will have more extreme responses during stressful situations that predispose them to injury.[34]

A model created by Williams and Anderson in 1997 stated that a potentially stressful situation will generate a stress response varying in intensity depending on the individual and how threatening the athlete perceives the event. There are potentially three categories of variables that may influence the strength of the stress response and further the likelihood of injury; personality traits such as anxiety and perfectionism, history of previous stressors such as major life events or previous injury occurrences, and coping strategies and resource such as psychological skill use and social support.[34] In conclusion the mechanism by which the stress response increases the occurrence of injury is through attentional and somatic changes to the individuals such as increased distractibility and peripheral narrowing, as well as the increase in muscle tension, fatigue, and reduced reaction time and coordination. This model has become the basis for research in regards to psychological influence and injury susceptibility.[32]

It is becoming more common for professionals to psychologically screen athletes. As the number of studies examining psychological influences increases, it is becoming more prevalent that negative life events can have either a direct or indirect influence on injury occurrence.[32] A study done by Gunnoe, Horodyski, Tennant, & Murphey in 2001 examined the effects of life events on the incidence of injury in high school football players. It was found that of the 165 total injuries that occurred, 87 of them were during practice and 78 during competition. It was determined that the presence of a high total negative life event score was indicative of injury status and injury frequency. Sixty percent of the athletes that were injured during the time of this study reported high total life event scores. These findings were supported in 2013 by Ivarsson et al. who determined that daily hassle had a direct impact on injury frequency that was further enhanced by the greater occurrence of negative life events and trait anxiety characteristics.

It can be challenging when trying to determine the effects of psychological stress on an individual since stress can affect a person's mental and physical state in many different ways. It has been found that with high amounts of stress during demanding tasks may cause peripheral vision and reaction times to decrease that can cause an athlete to miss important cues. This can also cause a decrease in perceptual sensitivity for centrally presented targets.[34] These effects on performance are only seem to be amplified in athletes who report more negative life events, social support, psychological coping skills or any combination of these factors. [32,34,35]

Poor psychological state can significantly alter how people respond in demanding situations. Athletes who have high levels daily life stressors and more negative life events along with low levels of social support and psychological coping skills could be left with fewer resources to handle stressful situations and thus decrease an athlete's level of perceptual sensitivity and a decrease in their peripheral vision. This may cause the athlete to take longer to respond to cues and complete motor patterns that were habitual. Instead athletes may make decisions and perform motor patterns in a delayed or incorrect fashion causing them to get injured in an otherwise normal playing condition. [32,34] Today, while many professionals support and advocate the measurement of psychological state in the athletic population, current psychological state is not always used in seasonal evaluations due to lack of knowledge and a lack of time availability.

Muscle and Joint Flexibility

In terms of intrinsic risk factors, lack of muscle flexibility is one of the most commonly proposed risk factors for the development of muscle injuries, especially in the lower extremity.[36] Despite previous findings, literature reviews and prospective studies looking at muscle flexibility as an indicator of injury are scarce and incomplete.[37] This may be due to the fact that flexibility is sport specific and that muscle tightness or soreness may alter measurements throughout the season making flexibility a variable that is hard to assess accurately.[36]

Inequalities in lower limb flexibility can affect lower limb length as well as alter the normal kinetic patterns of lower extremity functioning.[16] If an athlete has apparent abnormalities in muscle flexibility, the body will not be able to function correctly and will change its mechanics to accomplish the movement that is demanded. When muscle becomes tired, sore, or agitated due to its altered mechanics, the athlete is put at risk to for sustaining a lower extremity injury.[16]

Further, athletes with hyper flexibility may be at risk for injury because hypermobile athletes may lack the reflexes to activate muscles necessary to change posture, maintain desired mechanics, and may lack the ability to stabilize the body in a dangerous situation that may end up in an injury.[38] Examples of such events may be an athlete slipping, changing directions rapidly, or kicking a ball. In addition, if an athlete has a flexibility abnormality, not only will there be a change in the athlete’s mechanics but there also may be incorrect muscle activation patterns paired with a change in muscle reaction time further causing a potential injury.[38]

While there have not been many recent prediction models that look at the effects of flexibility on injury, there have been a few prospective studies that have attempted to examine the effects. Witvrouw et al. in 2003 examined flexibility in professional soccer players and the incidence of muscle injuries sustained during a season. It was found that out 67 of the 146 athletes studied sustained a muscular injury, majority of which were quadriceps and hamstring injuries with adductors being ranked third in occurrence. It was found that players who had less than 90 degrees in hamstring flexibility were significantly more likely to sustain a hamstring injury. The same was found true when evaluating quadriceps flexibility. These findings were supported by Krivicaks and Feinberg in 1996 who found a significant correlation between lack of flexibility and the development of lower extremity muscle injuries in college athletes.

Currently there is no scientifically based prescription for flexibility training protocols and no conclusive statements about the relationship between flexibility and athletic injury.[36] Athletic injuries are a combination of intrinsic factors within the athlete and extrinsic factors surrounding the athlete acting together at the opportune moment.[15] Abnormalities in flexibility may not be a sole predictor of athletic injury susceptibility. Additionally, athletes could arrive sore to practice or competition that may change an athlete’s current flexibility status. Increased stiffness may be associated with increased isometric and concentric force generation.[36] Further the athlete may be susceptible to altered mechanical patterns, altered muscular reaction time, and decreased visual awareness as the player becomes tired or as their emotions escalate during activity. Eventually, these intrinsic factors may combine with flexibility deficits, whether circumstantially decreased due to soreness or of normal limitations, causing an athletic injury.[4,15,20,37]

Core Stability and Strength

The core is defined as the anatomical box that contains the abdominals in the front, paraspinals and gluteal muscles in the back, the diaphragm as the roof, and the pelvic floor and hip girdle as the bottom.[40] The core serves as the center of the functional kinetic chain and is needed for muscular control around the lumbar spine and to help maintain functional stability during athletic movements. Stability of the lumbar spine and lower body often requires passive stiffness through ligaments and active stiffness through muscles. If one of the muscles are unstable to perform correctly or are injured then there may be a dysfunction that may lead to an injury.[41]

All core muscles such as the transversus abdominis and multifidi are needed for optimal stabilization.[41] The osseous and ligamentous structures provide stiffness to the tissue and, along with the thoracolumbar fascia, acts as "natures back belt" to support the spine and abdominal muscles. With contraction of the muscles, it acts as a proprioceptor to give feedback to the body during activities to protect the athlete from potential injury while the diaphragm serves as the roof and the final component of stabilization of the core.[41] When an athlete has adequate stability there is an increased efficiency and ability to transmit force that is created by the lower body though the trunk to the upper body safely.

Professionals have found that altered neuromuscular trunk and hip control during the execution of athletic movements may result in suboptimal limb joint mechanics, in forms of altered motions and loads, which increase the risk of injuries in athletics.[42] When made susceptible to external factors, the neuromuscular system must respond with compensatory muscle forces necessary to stabilize the lumbar spine and lower body to avoid injury.[43]

Previous studies have examined the effects of postural control and low back pain with the incidence of injury in athletics. Greene, Cholewicki, Galloway, Nguyen, & Radebold in 2001 examined 679 athletes, 18.3% of which reported a history of low back pain and 90% of them were deemed as being sport related. It was found athletes with a history of low back pain injuries were six times more at risk for sustaining another low back injury the following year. It has been found that athletes with a previous low back injury exhibit prolonged trunk muscle response time which has been found to cause not only recurring back injuries but injuries in the lower body as well.[45]

Both suboptimal endurance of the core muscles and low back dysfunction have been associated with impaired neuromuscular control of the body's center of mass and coordination of lower extremity muscles, as well as the elevated risk for lower extremity injuries.[46] Few recent prediction models have assessed the role of core stability and strength and the occurrence of lower extremity injuries even though it is widely accepted that the core controls the body during activity and protects it from becoming unstable and susceptible to injury. A prospective study by Wilkerson et al., in 2012, examined core stability and strength as a component of a lower extremity injury prediction model in collegiate football athletes. It was found that a low wall sit time and low trunk flexion hold time, which are valid assessments of core stability and strength, were indicative of a lower extremity injury. It was suggested that any delay in activating, or the inability to maintain the core muscles is likely to increase injury susceptibility.

In the literature there have been studies evaluating the effects of rehabilitation of strength, postural sway, position sense, and re-injury after an athletic injury. An early significant study done by Holme, Magnusson, Becher, Bieler, Aagaard & Kjaer in 1999 studied a cohort of athletes and found that in each individual there was a significant difference in postural sway between previously injured and non-injured ankles. Further, it was also found that there was a significant strength difference between the ankles. Athletes were separated into two groups; a control group and a group that was geared to training for postural sway, strength, and control. After the season it was found that only 7% of the training group suffered a re-injury while nearly 30% of the athletes in the control group sustained another injury. The theory that hip strength, postural sway, and control could dictate trunk, hip, and knee motions and loads to stabilized previously injured structures underlines the importance of hip and core strength and control.[42]

Bilateral Strength and Power Imbalances

Series of evaluations are done at various points each season to assess the abilities, health, and current status of an organization's athletes. With this information professionals are able to adjust training techniques in attempt to prevent traumatic and overuse injuries and ensure optimum performance and health.[48] While many tests are used to assess muscular strength and power in performance testing, there is little to no examination of the effect of bilateral muscle architecture and muscle performance imbalances on injury risk using functional tasks.[49]

Many different factors lead to the development of a muscular imbalance. It has been suggested that imbalances are likely related to the athlete's dependence on their dominant leg during cutting, pivoting, and jumping.[49] It is important that professionals keep in mind that what is considered the dominant leg for one task may not be the dominant leg for another. Therefore, what is deemed to be an acceptable degree of imbalance and what may lead to an injury is not well understood.[49] What is currently understood is that an imbalance that continues over time, with or without a history of a lower body injury, may become magnified over a season, leading to a greater accumulation of fatigue, micro trauma, and eventually injury.[50]

Bilateral muscular imbalances may result in unequal forces produced in opposing limbs during jumping and running. If there is a muscular imbalance, a unilateral movement that is frequently performed during sports may result in an athlete landing awkwardly on one leg and cause an injury.[49] In clinics and strength and conditioning facilities hop testing is often used as a performance outcome that reflects neuromuscular control, strength, and limb stability.[51] While few studies have used hop testing to predict injury occurrence, hop tests are frequently used to identify athletes with poor dynamic knee stability and to determine if an athlete will be able to successfully return to high level sports after ACL reconstruction.[52] In these studies the uninjured leg is used as a baseline for the injured leg. Once an athlete can single leg hop 70-85% of the distance of their uninjured leg then the athlete's muscular strength is considered "normal" which allows them to move forward into more sport specific training.[53]

Previous studies using the single leg hop for patient evaluation after ACL reconstruction have found that the single leg jump can effectively challenge the neuromuscular control of patients who have limb deficits and can accurately predict if an athlete will be able to return to sport after the injury.[54] In 2012, Logertedt et al. found that the single leg hop 6 months after ACL reconstruction significantly predicted self-reported knee function one year after surgery. Athletes who minimize their bilateral muscular strength deficits were more likely to be successful upon return to athletics and more likely to remain healthy for the following season. Further, in 1998 Petschnig, Baron & Albrecht found that regardless of when athletes, who underwent ACL reconstruction, were assessed for bilateral strength differences there was always a significant difference between the involved and uninvolved leg on all functional and isokinetic performance tests regardless of leg dominance. It was found that almost all of the patients had an inadequate leg symmetry index in the group assessed in the first 12 weeks after surgery while 28% of those assessed between weeks 13 and 54 showed asymmetries. This suggests that bilateral deficits may remain for over a year after reconstruction if the athlete does not undergo adequate rehabilitation protocols.

From the findings found through evaluation of athletes after ACL reconstruction, professionals have recently begun to assess muscular imbalances in healthy athletes with the goal to predict and further prevent the development of muscular imbalances that may lead to injury. In sports that develop a dominant leg, such as basketball and soccer, it is common to see muscle imbalances due to previous injury, neuromuscular control deficits, poor technique, inadequate loading and unloading of the lower limbs, or decreased bilateral strength.[48] Mangine et al. in 2014 found that there was a positive correlation between the number of games missed by professional basketball players and bilateral differences in the vastus lateralis. In 2009, Schiltz et al. compared explosive strength imbalances between professional and non-professional basketball players and found that the professional group displayed asymmetry above the 10% clinically significant cut off point for normal imbalances. It was also determined that players with previous injury consistently showed functional and isokinetic asymmetries.

There are few studies assessing bilateral strength imbalances in in healthy athletes.[49] Traditionally open kinetic chain evaluation techniques have been used as the primary tool to assess an athlete’s strength before and after an injury, readiness to proceed to a higher functional level, and ultimately return to sport after an injury has occurred.[56] Unfortunately, these tests may not provide adequate information. Instead functional tests such as the single leg hop test has been used to evaluate functional limitations, imbalances, control, strength, and stability of the lower leg. Athlete’s with inadequate one legged hop tests that reveal asymmetries of greater than 10%

bilaterally, or who are unable to jump 70-85% of their dominant leg, considers an athlete to be at an increased risk for injury during sports.[48,56,57] Identifying at risk athletes during the off season or at the start of preseason may help coaching staffs and sports medicine professionals intervene with training programs that may minimize the athlete's risk of sustaining an injury by correcting muscular imbalances before they become magnified and harder to correct (Brumitt et al., 2013).

Functional Movement Screen™

While evaluation of individual risk factors is the current standard for determining if an athlete may be predisposed to injury, it has been argued that evaluation of each individual risk factor does not take into account how an athlete actually performs functional movement patterns that are required for sport.[58] This suggests, that even if an athlete exhibits isolated individual risk factors, if there is no observation of functional movements then there is no way to know how the athlete actually performs and moves with these abnormalities. In reality, professionals may miss combinations of risk factors acting together that put an athlete at a greater risk for injury.

The Functional Movement Screen™ (FMS™) was created to fill the void between the pre-participation screenings for risk factors and performance tests by evaluating individual's dynamic and functional capacity.[59] This assessment requires athletes to exhibit an adequate amount of strength, flexibility, range of motion, coordination, balance, and proprioception in order to complete seven functional movements.[58] With the completion of this test professionals can use the results to assist in determining readiness to return to a sport after injury as well as offer a more realistic approach to injury prevention and performance predictability.[59]

It has been suggested by previous injury prevention studies that poor mechanics during sport is one of the leading causes of injury. It is for this reason, medical professionals should be seeking to understand athlete’s mechanics and potentially alter movement in order to not only increase performance but also decrease the risk of injury.[12,15] During the seven functional movements that are tested with the FMS^{TM}, athletes are scored on a scale of zero to three, three meaning that the athlete performed the movement with no mistakes or compensatory patterns and zero meaning that the athlete could not complete the movement or suffered from pain. It has been previously demonstrated that scores lower than a 14 on the FMS^{TM} scale are associated with injury occurrence.[61]

Many recent studies have used the FMS as a complete battery for functional screening and has been used to assess the occurrence of injury in various populations. Kielsel, Plisky, &Voight in 2007 sought to determine if the FMS^{TM} used during preseason screening measures could successfully predict the occurrence of injury in professional football players. It was found that the mean score of athletes who sustained a lower body injury was 14.3 points while the mean score for those who did not sustain an injury was 17.4 points. It was determined that the FMS^{TM} was successful at identifying the subjects at risk while minimizing athletes that were incorrectly identified as not being at risk. A sensitivity of .54 and specificity of .91 was reported. Further, it was found that athletes who exhibited a score below 14 were 11.65 times more at risk for sustaining an injury. Thus, it can be suggested by these results that the FMS^{TM} is an adequate tool when assessing functional movement and injury rates in athletics.

These results can be reinforced by a study done on injury occurrence in officer candidates by O’Conner, Deuster, Davis, and Pappas in 2011. It was hypothesized that officers that had longer training cycles and longer exposure times to strenuous activity would be at greater risk for suffering from an injury. When looking at FMS^{TM} scores it was determined that officers in the longer training cycle group, 10 weeks opposed to six weeks, that had a score of less than 14 on the FMS^{TM} had a 1.65 times more likely of sustaining an injury then those in their group with scores above 14. The same was found for officers in the short group. Officers who had less than a 14 were 1.91 times more likely to sustain an injury then those with a score above 14. Further it was concluded that 45.8% of the people with scores less than 14 suffered an injury compared to the 30% of those with scores greater than 14. Connections between length of training seasons, preseason, competition seasons, off seasons, and even high school sporting seasons along with incidence of injury can potentially be made from this study. This suggests that people who have longer training sessions may have a lower risk for injury then those with short seasons.[62] Athletes who have slightly longer training seasons may be able to develop better strength and endurance then those who have a shorter season and tend to rush through preparing for games and matches.

Nutritional Deficiencies and Insufficiencies

As suggested previously, most athletic injuries are multifactorial in nature. While examining different risk factors for injury individually can help provide a starting point for rehabilitation and prevention, there is often another variable, intrinsic factor, which may be interacting with that factor that may be help in the incidence of injury. In reality, sometimes focusing on one factor does not yield a true picture of the contribution that ends in injury.[12,15] While one factor alone may not present sufficient cause for injury by itself, it may exacerbate the effects of another that makes a sufficient cause.[15] One of these factors may be nutrition deficiencies.

Vitamin D

Research suggests that Vitamin D has an active role in many different realms; immune function, protein synthesis, muscle function, inflammatory response, cellular growth, and regulation of skeletal muscle.[63-65] While found to effect a person long term and leading to chronic injuries such as the development of osteopenia, osteoporosis, and stress fracture occurrence[63], sub optimal vitamin D levels may have larger effects on other intrinsic factors that cause injury.

Vitamin D is generally only acquired by the human body two ways; through the diet and through exposure to Ultraviolet B (UVB) radiation in the sunlight. Generally people who are consuming meat and fish products, as well as spending time in the sun, have adequate vitamin D levels. On the other hand, people who live far from the equator during fall and winter, play indoor sports, wear protective covering, sunscreen, and have darker skin pigmentation, as well as those who consume a vegetarian diet may still be at risk for a Vitamin D deficiency.[64,66,67] Hamilton, Grantham, Racinais, and Hakim in 2009 found that 90% of Middle Eastern sportsmen were vitamin D deficient between April and October even though they were located at latitudes favorable to high amounts of UVB light. In contrast, another study conducted at a less UVB favorable location found that 63% of athletes were vitamin D deficient in winter, compared to 12% in fall and 20% in spring in indoor and outdoor athletes.[69]

Today, there is no consensus for optimal Vitamin D levels. It has been agreed upon that less than 20 ng per milliliter is adequate to be considered a Vitamin D deficiency while 21 to 29 ng per milliliter is considered having relative insufficiency. People with relative insufficiency should be treated like they have a deficiency and start supplementation.[64,69]

In previous studies it has been found that without adequate amounts of Vitamin D only 10 to 15% of Calcium and 60% of phosphorus is able to be absorbed by the body.[64] The decrease in availability of these nutrients can potentially create further problems for the body. Generally it has been reported that osteoclasts and osteoblasts cannot be created thus the risk for fracture increases.[64] On a different note, a vitamin D deficiency can cause muscle weakness. This is due to the fact that muscles have vitamin D receptors and actually require vitamin D for maximal function.[63,64,70] Vitamin D helps transport Calcium in the muscle for muscular contraction. If type two muscle fibers, which are predominant in anaerobic and power sports, need calcium to work and don't have adequate supply of calcium being delivered by vitamin D then neuromuscular control could be altered predisposing an athlete to injury.[67,71] This could potentially affect postural control, reaction time, and strength further predisposing an athlete to injury.

Sometimes professionals fail realize the little things that affect an athlete. It has been found that psychological state greatly affects the athlete and contributes to the incidence of injury as well as reaction time and neuromuscular control[27,32,41] but vitamin D status may have an effect on all of these without medical professionals realizing it. It has been previously found that vitamin D deficiencies can be linked to an increase in schizophrenia and depression[72] and that low vitamin D levels can cause athletes to become tired, fatigued, and unmotivated. This can have a huge impact on psychological state and other functional performances simply because the athlete is not in the right state of mind or state of health. It can be concluded that while vitamin D deficiency may not be sufficient enough to cause an acute injury on its own, it may affect the athlete through other intrinsic factors and cause an injury to occur.

Iron

Iron is a trace mineral that is essential to the performance and health of an athlete.[73] While deficiencies in Iron are most often reported and studied in females, athletes who engage in strenuous physical activity are also known to be at increased risk for what is more commonly referred to as "sports anemia" or "sports induced anemia".[74-76]

It the literature, there have been various definitions of what is considered, iron deficient anemia, an iron insufficiency, and sports induced anemia. The World Health Organization has defined anemia as a reduced hemoglobin (HB) concentration less than 13 g/dL and ferritin levels of 30 μg/L.[77] While obtaining adequate levels of iron is easily done through a diet that is rich in red meats and protein, the prevalence of iron depletion in athletes still remains remarkably high due to a variety of risk factors. These risk factors include not only poor nutritional intake but also may be a result of hemolysis caused by repeated foot strikes, loss of blood and iron through menstruation in females, and iron loss through sweating.[78]

Iron is component of hemoglobin, whose main purpose is to transport oxygen and carbon dioxide in the blood. It is present in muscle as a component of myoglobin where it functions as an antioxidant and is important in the function of the electron transport chain as it produces adenosine triphosphate (ATP) for the body.[73] Clinical signs for the presence of iron deficiency may range from fatigue to decreased muscular performance and weakness. Further signs of sub optimal iron levels are impaired concentration and headaches.[79]

Studies examining the prevalence of sub optimal levels of iron have mostly dealt with screening females, endurance runners, and swimmers while the prevalence in anaerobic and male sports is less known.[78] An important study that was done by Renke et al. in 2012 compared two different male sports that are power based and have anaerobic components in nature; soccer and rowing. It was found that only 27% of the athletes showed absolute iron deficiency levels but that 70% of the athletes had suboptimal iron levels. Further, soccer players at the end of the season had ferritin levels that were 34% lower than rowing athletes. An important conclusion that was drawn from this study was the fact that the normal three week recovery period that usually results after a competitive season was not enough to fully allow ferritin and iron levels to recover and was followed by another decrease after pre-season training begun. This suggests that sub optimal iron levels may not only be sport specific but that they also may be very susceptible to change with training and competition levels so that they must be monitored closely.

Other studies have examined the prevalence of suboptimal iron levels in male athletes. Dubnov and Constantini in 2004 examined iron depletion and anemia in top level basketball players. It was found that while there was no significance between adolescent and adult players, that adults had significantly lower mean transferrin levels and high mean ferritin levels. Merkel et al. in 2005 examined the prevalence in strenuously trained athletes who participated in various sports. It was found that the type of strenuous activity, aerobic training compared to anaerobic training, can explain the occurrence of suboptimal iron levels. Amongst these athletes, it was found that 18.5 % and 18% exhibited levels of suboptimal hemoglobin and ferritin levels respectively, while only 1.4% and 7.4% exhibited levels of hemoglobin and ferritin levels respectively that were categorized for pronounced anemia.

Since iron presence in the body is essential for the transport and creation of ATP for physical activity, athletes who are low in iron levels will not only be susceptible to performance decreases but may also become susceptible to an injury that may chronic or even acute in nature. Without the availability of energy to perform, athletes may experience muscular injuries and unexplained muscle soreness that may not have any apparent cause in nature that may lead to traumatic injuries.[80] Further, like Vitamin D, Iron affects other intrinsic factors that may make athletes susceptible to injury. Changes in reaction time, neuromuscular control, strength, and variations in psychological status due to low iron status in the body may cause an athlete to sustain an injury. [27,32,41] Further, iron repletion has been shown to improve overall vitality, mental health, and decrease fatigue along with increase performance.[81]

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III. Methods

Participants

This prospective cohort study included 225 male, Division I football players who were present and participated in pre-participation measures before the beginning of preseason training for the 2014 (n= 113) and 2015 (n=112) seasons. All athletes at the time of data collection were part of the same National Collegiate Athletic Association (NCAA) Division I athletic program and were injury free at the beginning of data collection.

Athletes who participated in more than one season were treated as separate cases for each season. This is a common and accepted protocol for multi-year studies and prediction models.[7,24] Demographics for athletes in 2014 were as follows: 19.69 ± 1.44 y., 1.88 ± .07 m., 106.91± 22.69 kg. Demographics for 2015 were: 19.68 ± 1.39 y., 1.87± .07 m., 108.26± 22.31kg.There were no statistical differences between the cohorts. Among the 225 athletes who were included in this study, 83 participated in both seasons, and 59 participated in a single season.

Data Collecting Location, Ethics, Consent, and History

Demographic and performance testing was conducted at various locations at an NCAA Division 1 University. Locations included athletic team's specific training rooms, the athletic department's sports psychology office, and respective strength and conditioning facilities. All testing procedures were approved by the University of Arkansas Institutional Review Board (Appendix). Data that was collected on the participants was previously collected data by certified and trained medical and non-medical professionals. All data was collected in a de-identified manner to avoid identity exposure of the athletes.

Variables

Data collected at the start of each season comprised of their regular preseason evaluation protocols. This included documentation of position, previous injury, age and experience level, height, weight, neurocognitive abilities, psychological status, flexibility status, core stability and limb strength, functional movement status, and nutritional status. Relevant measures were used to calculate each athlete's Mass Moment of Inertia (MMOI) and Body Mass Index (BMI) for further comparison.

At the conclusion of the athletic season, data was collected from relevant personnel, Athletic Trainer, Sports Psychologist, or Strength and Conditioning Specialist, to document if the players sustained an acute lower extremity or core sprain or strain that season, what time of the season they sustained their first injury, and the time loss that resulted from the injury. The athletic team's staff was also contacted to quantify each athlete's game exposure for the season, in terms of starter status for the season.

Testing Protocol

Injury Definition and Documentation

There is no concrete definition of an injury thus the definition for the event varies from study to study.[1,4] For the means of this study, an injury was defined as an acute core or lower extremity sprain or strain that required the attention of an Athletic Trainer or medical professional.[1,12] Injuries that were sustained by the players during the season were documented by the University's Athletic Training Staff and were relied upon for accurate documentation.

Injuries that were sustained by athletes were further broken down into groups depending on severity of the injury; *all injuries reported (ANY)*, *limited participation (LP)*, and *removed (OUT)* from one or more practices or games. This was due to the fact that some injuries are sometimes not severe enough in nature to seek medical treatment or receive an alteration in physical activity.[4] The NCAA states that an injury has been sustained when an athlete is unable to participate in sport and must completely miss at least one practice or game.[3] Some types of injuries were excluded from this study in order to fully encompass the injuries that are most likely to be due to a deficit neuromuscular response whether it resulted from collisional impact or dynamic movement in nature.[14] Injuries excluded were breaks, fractures, or other injuries that were chronic in nature.

Each injury was recorded in terms of side and body part injured to further classify types of injuries with a coded number. Further, time of season that the injury was sustained, preseason, in season, or post season, was recorded along with injury severity with a coded number.

Experience Level

It was found by Turbeville et al. in 2013 that an increase in football experience was associated with a 40% to 60% increase in injury risk for every one year increase in experience. Athlete's competition level was therefore recorded with the relevant number that suggests how many years that the athlete has been training with their respective team. Experience level was documented from information given in the athlete's preseason physical examination forms. A question in these forms asked the athletes how many years they had participated at the collegiate level according to the NCAA. These documented numbers ranged from zero, meaning that this was their first year of eligibility; to five meaning that they were in their fifth year with a collegiate team. Athletes who responded that this was their fifth year of competition signified that a redshirt had been awarded for a previous season. All athletes who received a red shirt were documented.

It is not uncommon for athletes to receive “red shirt” status as a freshman or during another season for various reasons. These issues can range from educational issues, recovery from a previous injury, to occurrence of a new injury, or many other medical reasons. Athletes who are of red shirt status practice with the team and continue to be a part of the team as all eligible athletes would, if possible. The only difference is that the athlete does not suit up or play during that competition season. Thus, they do not have any game exposure to be documented by statisticians.

Game Exposure

Game exposure was documented by coaches and team statisticians during the season. Game exposure was classified as the occurrence of “starter status” in a game during the season.[14,24] For the purpose of this study, game exposure could not be quantified before the season and had to be collected after competition season was over. This required that the staff was able obtain reliable and accurate data to be reported for the purposes of this study. Starter status was documented as either a “yes” or “no” occurrence. Current predictions models have aided in supporting the claim that increase game exposure via experience and potential starter status has been linked with increased risk for injury.[14]

Previous Injury History

Previous injury data was obtained from athlete’s pre-participation examinations as well as from the university’s sports medicine injury documentation software database. As with sustained injury documentation, previous injury history was defined as an acute core or lower body extremity strain or sprain that resulted in the attention from an Athletic Trainer or health care professional.[1,14] Injuries that were previously sustained were reported by the athletes, in the case of transfer or transitioning from high school to college athletics, or were documented previously by the university's athletic training staff. For the purposes of this study it was assumed that there was reliable reporting and documentation of such injuries.

Similar to documentation for injuries sustained during the season, previous injuries were recorded in terms of side and body part injured to further classify types of injuries with a coded number. Time of season, severity, and year of injury were not consistently reported amongst documentation so this was not collected for the purposes of this study. Regardless, it has been shown by many previous prediction models and injury prevention studies that the mere event of a previous injury will increase the chances of an athlete sustaining another injury.[9,15,16,20]

Body Mass Index and Mass Moment of Inertia

Body Mass Index (BMI) is intended to provide an indication of how overweight a person is by adjusting body mass for height.[9] BMI is calculated as Body Mass (kg)/Height^2 (m). This calculation has been previously used to determine estimated BMI and higher values have shown to significantly put athletes at risk for a lower extremity injury.[9,22]

Players can be categorized using age and gender-specific BMI normative data obtained by the Center for Disease Control and Prevention (CDC). According to the CDC, underweight is determined as being at or below the fifth percentile for age, normal weight is determined as greater than the fifth percentile to less than the 85th percentile, at risk for overweight is the 85th percentile to less than the 95th percentile and overweight is greater than or equal to the 95th percentile.[26] It should be noted that BMI is not always reliable in determining how overweight a person is. BMI is not sensitive to the amount of muscle that a person possesses which may cause BMI values to suggest that an individual is overweight or at risk when they are not.[9]

Mass Moment of Inertia (MMOI) determines the height of a player's center of gravity above the ground. It has been found that the larger a person's center of mass and the higher it is located above the ground, the more likely the individual will be to sustaining an injury.[23] MMOI is calculated as Mass (kg)*Height (m^2). While this is the accepted way to calculate MMOI this equation suggests two things; that the center of mass and the proximal and distal endpoints are assumed to be aligned in the human body, and the inertia tensor is assumed to be principal in the axes of the segment which may make MMOI values different from reality.[82]

While both BMI and MMOI have some error associated with their implementation, they are both protocols that are widely used by various biomechanical, sport, and healthcare professionals.[9,22,82] For this study, height and weight information was collected from pre-participation examination forms and paperwork to calculate both BMI and MMOI for each athlete.

Neurocognitive Function

Evaluating a person's processing speed, working memory, attention, and concentration through ImPACT has been shown to be a reliable and valid method for examining neurocognitive performance.[28-30] These tests are usually administered as part of pre-participation examinations and following a concussion or other mental injury in order to develop a baseline of current neurocognitive status for individuals.

For the purposes of this study ImPACT (Version 3.0 ImPACT Applications Inc., Pittsburgh, Pennsylvania) was used for the evaluation of the athlete's neurocognitive status. Tests were given at the university at the beginning of their first year on their respective athletic team during preseason physical evaluations. If the athlete did not sustain a head injury, the ImPACT test was not again administered, but if an athlete ended up sustaining a head injury more recent baseline data for after the injury was available. It was assumed that each athlete was administered the test in a private office or laboratory and that the test outcomes were valid. For data collection four composite numbers were recorded; reaction time, processing speed, visual memory, and verbal memory.[83] This protocol is in comparison with previous studies when determining neurocognitive performance.[27,31]

The verbal memory and visual memory composite scores represent the average percent correct for associated tasks administered through the test. The reaction time composite score represents the average response time (milliseconds) on reaction time based tests while the processing speed composite score represents the weighted average in seconds of tasks involving memory.[29] Test-retest reliability for ImPACT ranges from .66 to .85 for verbal memory, .65 to .67 for visual memory, .75 to .88 for processing speed, and .62 to .79 for reaction time index.[83,84]

The purpose of using ImPACT following post-concussion is to determine if an athlete is ready to begin return to play protocols as concussion symptoms subside. The aim of this protocol is that athlete's neurocognitive status should return to baseline levels post injury.[28,29] While it is strongly advocated that a new baseline measure be taken each year, or more for younger adults, it has also been suggested that as an individual ages, neurocognitive performance will begin to stabilize within an individual and can remain reliable for about two years.[84] This suggests that it may be less important to re-administer the ImPACT test each year since individuals who did not sustain a neurocognitive injury would remain at a constant level while athletes who did sustain an injury would likely return to normal neurocognitive levels or would have received new baseline data.

Current Psychological State

It has been found in many studies that suboptimal psychological state may cause an athlete to become more susceptible to injury.[32,35] Today, there are many forms and methods of measuring someone's current psychological state that are fairly valid and reliable. Since there are so many different versions of psychological testing protocols it often makes it hard to compare psychological outcomes. It is also important to realize that psychological state alone does not often make an athlete susceptible to an injury, in reality it is often a factor that causes the development of peripheral vision narrowing, increased distractibility, lack of ability to respond to important and immediate cues, a decrease in reaction time, increased fatigue, and decreased neuromuscular control.[32,34,35]

For the purposes of this study, psychological status was measured using the Multidimensional Health Profile-Psychological Functioning (MHP-P) Instrument (Psychological Assessment Resources, 1998, Florida). This instrument was utilized due to the fact that this is the test that the sports psychologist at the university administered to the athletes as part of their assessment protocol. It was assumed that this test was administered to each athlete at the beginning or prior to preseason training and that it was administered in a private office or other private environment to allow valid answers. It was also assumed that the athlete answered each question honestly. Results were interpreted by the sport psychologist upon completion. For the purposes of data collection four composite scores were collected; total life stress, coping skills, psychological distress, and social resources.

The MHP-P was developed to provide a brief but comprehensive assessment of psychosocial characteristics relevant to mental and physical health. This simple paper, pencil test aims to assess the psychological factors that have been found to play a role in healthy functioning; life stresses, coping skills, social resource availability, and total mental health.[85]

The main purpose of the MHP-P is to detect ongoing environmental challenges and poor reaction tendencies rather than fully elaborate cognitive appraisal habits and motivational directives that are implied by modern accounts.[85] Thus, the MHP-P examines the number of stressful events experienced over the previous year, the perceived stressfulness of those events, and a single rating of the perceived impact of stress on one's life over the prior year, global stress.[85]

The mental health component of the MHP-P aims to address the symptoms considered to affect the global mental health status of a person; anxiety, depression, guilt, anxiety, cognitive disturbance, and somatic complaints. These categories were grouped into two larger components; psychological distress and life satisfaction.[85]

The social resources component of the MHP-P aims to address the aspects that have generally been focused on in terms of social resources by other psychological testing protocols; support availability, support satisfaction, and enacted support. This also led to the measurement of the basic forms of support including emotional support, informational support, and tangible support. Further total negative social exchange experience was also documented and used to help create the social resources composite score.[85]

The last component, coping skills, refers to a person's ability to deal with the threat posed by different life stresses. The behaviors measured are either problem focused, strategies aimed at problem solving or altering the source of stress, or emotionally focused, strategies designed to control or reduce a person's emotional responses to the stressful events, in nature so the MHP-P strives to distinguish between these different coping strategies.[85]

In terms of assessing the retest reliability of this form a series of three trials were carried out to examine the psychometrics of the MHP-P and create relevant changes to make it a better testing battery. Retest reliability measured for the best versions of the MHP-P test was reported. Measurements for all the subdivisions of the mental health component ranged from .49 to .88

(p<.001), the subdivisions of the social recourses component was .62 to .82 (p<.001), coping skills was .65 (p<.001), and life stress was .68 to .86 (p<.001).[85]

Validity of this form was also reported with this three trial study. For mental health, all validity correlation coefficient for the subscales were all significant beyond the .001 level. These coefficients ranged from .37 to .69 disregarding negative or positive correlation values. For life stress all correlational values were also significant (p<.01) ranging from .43 to .49. In terms of coping skills six of the thirteen original subscales proved to be valid and significant. Due to this these six components were used to create the coping mechanism category. Correlational values from these subscales ranged from .24 to .33 (p<.01). Lastly, the social resources component were significant to from the p<.001 to p<.01 levels. These correlational values ranged from .30 to .40.[85]

Muscle and Joint Flexibility

Lack or excessive muscle flexibility is one of the most commonly proposed risk factors for the development of muscle injuries, especially in the lower extremities.[36-38] Despite this, literature reviews and prospective studies looking at muscle flexibility as an indicator of injury are scarce and incomplete.[37] A reason for this may be due to the fact that flexibility is sport specific and that muscle tightness or soreness may alter measurements throughout the season making flexibility a variable that is hard to assess accurately.[36]

For the purposes of this study, abnormalities in flexibility were assessed through pre-participation examination records. Lower limb muscle flexibility and joint flexibility abnormalities were recorded for each individual based on the limb affected and its corresponding side. Athletes were evaluated by a licensed physician. It was assumed that the information documented during pre-participation examinations were thorough, accurate, and reliable for each athlete. It should be noted that gross lower limb flexibility was only measured during the athlete’s first season at their institution. If an injury was acquired at some point during the season, new flexibility measures for that limb were documented but new baseline measures were never documented at the start of the next season. For this reason, in order to remain consistent measures, data was only obtained from pre-participation physicals from the athlete’s first year.

Core Stability and Strength

Similarly to psychological factors, core stability and strength is not a variable that would cause injury on its own. Rather, a lack in strength would combine with other internal factors that may cause the risk for injury to increase substantially. Both suboptimal endurance of the core muscles and low back dysfunction have been associated with impaired neuromuscular control of the body’s center of mass and inhabitation of lower extremity muscles, as well as the elevated risk for lower extremity injuries.[46] Few recent prediction models have assessed the role of core stability and strength and the occurrence of lower extremity injuries even though it is widely accepted that the core controls the body during activity and protects it from becoming unstable and susceptible to injury.

For the purposes of this study, core stability and strength was measured through the front plank to fatigue. This test was administered by the strength and conditioning coaches for the team as part of their preseason fitness baseline testing regimen. Athletes were to perform the front plank test until form was broken or the athlete decided to quit the test. The time was then recorded for the athlete. For this study, it must be assumed that each professional testing the athletes were using the same criterion for grading and using the same procedures to enact the test for each athlete so that reliable and valid data could be collected.

Testing procedures for the plank test were as follows: the athlete assumed the forearm plank position with elbows in contact with the ground so that the humerus and the forearm created a 90 degree angle underneath the shoulders. Hands were placed in front of the forearm in a neutral position and the body was supported only by the forearm/hand junction and the toes. When time began the athlete assumed a rigid anatomical position in which the body remains in a straight line that lined up the shoulders, hips, gluteus, thighs, lower leg, and ankles in a straight line. The test was stopped if the athlete voluntarily quit the test, if the athlete failed to maintain the proper position, or if the athlete exhibited ill effects such as dizziness from the test. This protocol is in similarity to protocol carried out by previous studies.[86,87]

It should be noted that there have many different ways in current research to measure core strength and stability.[14,41] Regardless, it has been found that adequate strength and endurance of the core musculature can significantly decrease the risk for injury.[42] The front plank test has been found to be a functional and valid test to assess core stability and strength because it requires the simultaneous activation of the entire anterior muscular chain.[87] It has been shown that adequate strength of anterior and posterior chains will help decrease the risk of injury and even increase muscular performance.[41] The front plank test to fatigue is a valid test for determining if an athlete has a strong core. It has been reported to be significantly correlated with the visual analog scale (r=-.63) and Oswestrey Disability Questionnaire Scores (r=- .56) thus helping determine that the prone plank test correlates well with disability and weakness of the core musculature. Further it has been shown to have a test retest reliability of .78.[88]

Bilateral Strength and Power Imbalances

In clinics and strength and conditioning facilities hop testing is often used as a performance outcome that reflects neuromuscular control, strength, and limb stability.[51] For the purposes of this study the single leg broad jump was used to quantify lower limb explosive strength and power. Distances jumped for right and left lower extremities were compared to determine the incidence and extent of strength and power differences.

This test was administered by the strength and conditioning coaches as part of the team's preseason fitness baseline testing regimen each season. For this study, it must be assumed that the strength and conditioning coaches used the same testing protocols, knew what was determined as an acceptable jump, and that their results are both reliable and valid for each player.

Testing protocols for the broad jump were as follows: Athletes were asked to stand with their toes behind a line drawn on the weight room floor. They were then asked to stand on the leg being tested before jumping as far as possible and then landing on two feet to decrease chance for injury. They were allowed to perform up to three trials on each leg before the best trial for each extremity was recorded. Measurements were taken from the distance behind the heel closest to the starting line. Trials did not count if the athlete was unable to control the landing without moving or if another limb including hands or glutes, touched the floor. This is in line with protocols done in other studies.[53,55]

It should be noted that while few studies have used hop testing to predict injury occurrence, hop tests are frequently used to identify athletes with poor dynamic knee stability and to determine if an athlete will be able to successfully return to high level sports after anterior cruciate ligament reconstruction.[52] It is from these studies that most reliability and correlational data is derived. Reliability statistics for the single leg broad jump have recently been presented as having the highest overall reliability of all hop tests of .92. A longitudinal validity based off of limb symmetry index change scores were 6.5% (95% CI4.5–8.5) for the single leg hop test.[89]

This shows that the single leg broad jump is a reliable and valid way of assessing lower limb strength and power that remains accurate over time.

Functional Movement Screening

It has been suggested that evaluation of individual risk factors does not take into account how the athlete performs the necessary functional movement patterns that are required for sport.[58] It was for this reason that the Functional Movement Screen^{TM} (FMS) (1995) was created. The FMS requires athletes to exhibit strength, flexibility, range of motion, coordination, balance, and proprioception in order to complete seven different functional movements. [58-61]

The FMS^{TM} was administered by the strength and conditioning coaches as part of the team's preseason fitness baseline testing regimen each season. For this study, it must be assumed that the strength and conditioning coaches used the same testing protocols, knew what was determined as an acceptable jump, and that their results are both reliable and valid for each player. For data collection purposes, only the final evaluation score was documented for each player.

Protocols suggested by the developers of the FMS^{TM} were followed as utilization of the FMS^{TM} protocols requires specific training to be done properly. The seven movements utilized in the screen are the deep squat, hurdle step, in-line lunge, active straight leg raise, shoulder mobility, trunk stability push-up, rotary stability, and three different unscored impingement clearing tests.

In terms of reliability and validity of using the FMS^{TM} to assess functional movement ability there have been many studies that have proven its worth and accuracy. Since the FMS^{TM} is often given by different individuals as well as given by the same individual for each athlete it is important that the reliability between administrators is consistent. The reliability for grading a live case versus a video session has been reported at .92 while the test-retest reliability was .6. Unfortunately, this study reported that the interrater reliability was poor, .38.[90]

Another study reported moderate intrarater reliability of .754 as long as the individuals had experience and were certified in the functional movement screen.[91] This means that the test is more reliable and valid amongst more experienced individuals and it can be suggest that the test should be given to all athletes by the same person in order to decrease variability and increase the reliability. In terms of ability to predict athletic injury has presented a specificity of .76, sensitivity of .42, and a positive predictive value of .61 when the standard FMS^{TM} cut off score of 14 was used.[61] This suggests that the FMS is pretty good at identifying athletes who are susceptible for injury but it does wrongly classify a good amount of athletes susceptible who actually do not suffer from an injury.

Nutritional Status and Deficiencies

Nutritional status is often a concern in athletics when attempting to prevent injury. Often athletes who have a suboptimal nutrition status will go unidentified and end up suffering from a serious injury or illness that can often terminate an athlete's career. While effects are different depending on the deficiency, some effects can be fatigue, musculoskeletal injuries, fracture, osteoporosis, depression, and potentially cancer.[63,73]

For the purpose of this study, nutritional status was determined from each athlete's blood work that was done at the beginning of the season. Blood work was taken by a Physician's Assistant. If an athlete presented any deficiencies in any nutrients it was logged into the database using a previously identified code. It is assumed that the athlete's bloodwork was the first and earliest bloodwork performed and that if an athlete was indeed deficient in their nutritional status that immediate protocols were enacted in attempts to rectify the deficiency for the safety and health of the athlete.

Blood sampling is the most common way and widely accepted way for health professionals to assess different components of people's blood status. Most health professionals require that individuals do not engage in any physical activity from 12 to 24 hours before the assessment and that they fast so that blood levels do not change due to dietary factors.[74,92] Usually about 10ml of venous blood is taken for examination purposes.[78] Blood sampling is usually used because it is a less invasive way of assessing nutritional status, is practical for daily practice, and has been found to be highly correlated with more invasive measurements as long as certain variables are held constant.[93]

When measuring vitamin D levels, insufficiency was accepted to be less than 29 ng/ml and under 20 ng/ml was diagnosed an a deficiency.[64,69] Athletes who were considered insufficient or deficient were both included for the purposes of this study. It has been found that there is an association between vitamin D deficiency and insufficiency and injury occurrence ranging from .21 to .57.[94]

While measuring Iron levels is best measured through bone marrow samples, it is also extremely expensive and an invasive procedure. Therefore, the measurement of serum ferritin has been accepted as a reliable marker for iron store depletion and is well correlated with bone marrow iron stores.[93] The World Health Organization has defined anemia as a reduced hemoglobin (HB) concentration less than 13 g/dL and ferritin levels of 30 μg/L.[77] For the purposes of this study, athletes who had an iron deficiency and insufficiency were included as it has been found that even athletes who have mild insufficiency may begin to exhibit negative side effects such as performance deficits and fatigue early on.[74]

Data Analysis

Athletes were dichotomously categorized as injured or uninjured for data analysis. Data was analyzed using SPSS (version 22; SPSS, Inc, Chicago, IL). Once data was imported into SPSS receiver operating characteristics (ROC) analyses was used to establish cut points for dichotomization of potential predictive variables. ROC derived cut points were used do classify athletes as either high-risk or low-risk. Cross tabulation analysis was used to calculate the Odds Ratios, Specificity, Sensitivity, and Significance level for each predictor variable. Backward stepwise logistic regression analysis was then used to identify the best combination of predictors and another ROC analysis was created to identify the best number of positive factors to distinguish athletes who got injured from those who did not. Another cross tabulation analysis would reveal the models Odds Ratio, Significance level, Specificity, and Sensitivity. A confidence interval (CI) was also created to assess the magnitude and precision of odd ratio values for the model. Cox Regression, or proportional hazards regression, was used to investigate the effect of several variables upon the occurrence of injury. This was used to quantify the probability for injury occurrence and timing throughout the duration of the football season.

Further, the Fisher exact 1-sided test was used to identify those variables that best predicted injured status using a 1-sided $P < .25$ test. This analysis provided what could be determined as the best "predictive model" for injury in this cohort. Typically a value of .05 to .1 is utilized in statistics but it is often accepted in the realm of predictive modeling that you utilize a significance level of .25. A benefit of using this significance level is that researchers are allowed to simulate a T test that allows more predictability on the higher risk realm of injury predicting to better encompass at potential at risk athletes. These protocols utilized were in correspondence of recent previous injury prediction models methods.[14,24]

It should be noted that because game exposure was not able to be quantified until after the season had ended that it was excluded from analyses that were limited to potentially modifiable injury risk factors. ROC analyses cannot be used to establish cut points until after the season as well. This is due to the fact that number of athletes who sustained injury is not determined before the season. It is for this reason that the 75th and 50th percentiles were also evaluated as cut off points for potentially modifiable injury risk factors. These protocols were also in correspondence to other prediction model studies.[14,24]

From this data and proposed prediction models the sensitivity, specificity, odds ratios, and relative risk would be calculated for each proposed model and each individual factor until the best was determined using univariate analysis protocols. Cox Regression, or proportional hazards regression, was used to investigate the effect of several variables upon the occurrence of injury. This was used to quantify the probability for injury occurrence and timing throughout the duration of the football season. Accuracy of these models was assessed by comparison of actual injury incidence through Kaplan Meier Analysis. In order to eliminate variable interactions cross tabulation analyses were ran between all predictive variables against injury incidence. All of these protocols are in comparison with a recent previous study that suggests the optimal way to design cohort studies. It has been strongly suggested that cohort studies are ideal for assessing multiple predictive factors before injury-risk exposure, which then can be analyzed separately and collectively for their value in predicting outcome.[12,15,95]

For the entire cohort a model was created using a different definition of injury occurrence; *No Time Loss (NTL), Limited Participation (LP),* or *removed(OUT)* from one or more practice or competitions (NCAA definition). To assess whether sustaining an injury the previous season is indicative of another injury the next season, another model was created using the demographics of athletes who played during the second season against previous injury occurrence in the first season. Lastly, in order to assess potential risks that could be modified for athletes who are injured during multiple seasons another analysis was created for only the athletes who were injured during the first season against the potential for another injury the second season.

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IV. Manuscript

A Prediction Model for Core and Lower Extremity Injuries in Collegiate Football Players

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A Prediction Model for Core and Lower Extremity Injuries in Collegiate Football Players

ABSTRACT

Context: Various intrinsic factors such as high exposure, poor endurance of core muscles, previous injury, strength deficits, suboptimal neurocognitive function, and orthopedic abnormalities have been found as predictors for sprains and strains among collegiate football players. ***Objective****:* Assess the applicability of pre-participation assessments as predictors of core or lower extremity injury. ***Design****:* Cohort Study. ***Setting****:* National Collegiate Athletic Association Division I football program. ***Patients or Other Participants****:* Athletes who underwent mandatory pre-participation examinations before preseason football training over two consecutive seasons (n=225). ***Main Outcome Measure(s):*** Associations between preseason protocols and injury incidence for core and lower extremity injuries were established for 225 players using three different injury definitions; all injuries reported (ALL), limited participation (LP), and removed (OUT). Receiver operating characteristic analysis was used to establish cut-points that classified cases as high-risk or low-risk for injury incidence. Logistic regression and Cox regression analyses were used to identify a multivariable prediction model for injury. ***Results****:* A 4-factor model (FM) for ALL identified ≥2 Positive Factors for differentiating between injured and uninjured athletes (*P*<.001, OR=3.21; 90% CI 1.98, 5.20 , Sens=77.3%, Spec=48.5%). A 3-FM for LP identified ≥1 Positive Factors to be the criteria (*P*<.004, OR=2.41; 90% CI 1.41, 4.10, Sens=82.8%, Spec=33.3%). A 3-FM identified ≥2 Positive Factors for OUT to be the criteria (*P*<.012, OR=2.25; 90% CI 1.27, 4.00, Sens=75.4%, Spec=42.3%). A 4-FM identified =4 Factors to be the standard for injury in the previous season (*P*<.001, OR=8.61; 90% CI 4.00, 18.53, Sens=58.5%, Spec= 85.9%). A 4-FM identified ≥3 Factors for subsequent injuries during both years (*P*<.011, OR=8.40; 90% CI 2.00, 35.70, Sens=44.4%, Spec=91.3%).

***Conclusions**:* Injury definition appears to be important for identifying risk factors for football injuries. Additionally, there are modifiable risk factors that can be determined from previous season injury and for athletes who are injured in consecutive years.

Key Words: injury prediction, injury prevention, injury risk

INTRODUCTION

It has been stated that injury is simply an inevitable consequence of sport participation.[1] Every year seven million adolescents, ages 14 to 18, take part in high school athletics while there are also over 420,000 college athletes in the NCAA. [2,3] While athletics promote good health, they can also be dangerous in the form of accidents and injuries. These injuries can result in the failure to achieve one's goals, increased medical treatment and costs, absence from school and work, permanent psychological distress, and early termination of athletic careers.[4]

Various studies have surveyed the incidence of athletic injuries to define the scope of injury. Unfortunately, reduction of injury burden cannot be accomplished if nothing is done to prevent injury.[5-7] Serious injuries, involving structures such as the anterior cruciate ligament, are a growing concern in sports that include high rates of contact paired with pivoting and cutting.[8] Other injuries to the lower extremities, in the form of hamstring strains and ankle sprains, are also becoming more prevalent.[5,9] Agel & Schisel (2013)[10] found that collegiate preseason practice injury rates were 6.3 per 1000 game exposures with injury rates climbing with increased level of competition. Turbeville et al. (2003)[11] found that increased injury rates even extend into high school sports when looking at 132 high school football players who sustained injuries during a football season; 54% of injuries were sprains and strains, 17% were contusions, and 11% fractures.

Today, most research is conducted to examine the incidence of injury to then create training protocols allowing for injury prevention instead of identifying the predisposing factors that may make an athlete susceptible to injury.[6,7] Unfortunately, conclusions and ideas can only be determined from athletes who have already suffered an injury. The most commonly cited model for sports injury prevention was by Van Mechelen in 1992[4] suggesting that prediction models should operate in a sequence; first identifying the incidence of injury, identifying the common factors and mechanisms associated, introducing measures to reduce future risk, and reevaluating measures and modifying them as necessary. Further, Meeuwisse, et al. (2007)[13], suggested that each individual has their own particular set of factors that predispose them to injury that are dynamic and can change frequently.

Intrinsic risk factors can be defined as factors that act from within the athlete; strength, age, neuromuscular control, individual anatomy, and previous injury. *Extrinsic risk factors* are factors that act from the outside to amplify the intrinsic factors that cause injury; playing surface, weather, practice versus game, and playing equipment.[1,5,6,13] The combination of these factors completes the chain of events and causes the athlete to enter the cycle of sports injury.[13] It has been suggested that professionals should seek to modify intrinsic factors because there is no way to guarantee control over external factors that occur each day.[13]

While there are many definitions of a *"sports injury",* it is widely accepted that an injury has been sustained when an athlete is not able to fully participate in sport warranting an evaluation that requires medical treatment until full participation can be resumed.[1] The NCAA states that an injury has been sustained when an athlete is unable to participate in sport, missing at least one practice or game.[3] Additionally, it should be noted that many athletes may approach the medical staff with an injury that warrants an evaluation but does not result in missed or modified time in practice.[1,13]

The purpose of this study was to assess the value of different variables that have been shown to be potential risk factors for core and lower extremity sprains and strains in collegiate football players. A secondary purpose was to identify the strongest set of predictors for a cohort of athletes to categorize these athletes as either high risk (HRisk) or low risk (LRisk) for injury occurrence which could be used as a way to identify those susceptible to injury over the course of a season. A tertiary purpose was to assess whether definition of injury occurrence changes the set of potential predictive factors and the risk of injury occurrence.

METHODS

Study Design and Participants

This retrospective cohort study included 225 male, Division I football players who participated in pre-participation measures before the beginning of preseason training for the 2014 (n= 113) and 2015 (n=112) seasons. All athletes at the time of preseason screening were part of the same National Collegiate Athletic Association (NCAA) Division I athletic program and were injury free.

Athletes who participated in more than one season were treated as separate cases for each season. This is a common and accepted protocol for multi-year studies and prediction models.[9,13] Demographics for athletes in 2014 were as follows: 19.69 ± 1.44 y., 1.88 ± .07 m., 106.91± 22.69 kg. Demographics for 2015 were: 19.68 ± 1.39 y., 1.87± .07 m., 108.26± 22.31kg.There were no statistical differences between cohorts. Among the 225 athletes included in this study, 83 participated in both seasons, and 59 participated in a single season.

Demographic and performance testing was conducted at various locations at an NCAA Division 1 University as part of pre-participation protocols mandated by the university's policies. All testing procedures were approved by the University of Arkansas Institutional Review Board. Following approval, de-identified medical data from preseason screening protocols was obtained from individual files. At the conclusion of the athletic season, incidence of injury was obtained from relevant personnel to identify players who sustained an acute lower extremity or core sprain or strain. Date the injury first injury was sustained, and time loss that resulted from the injury was also recorded.

For the purposes of this study, an *injury* was defined as an acute core or lower extremity sprain or strain that required the attention of a Certified Athletic Trainer or medical professional.[1,12] Injuries were further broken down depending on severity of the injury; *all injuries reported(ALL)*, *limited participation(LP)*, and *removed(OUT)* from one or more sessions. This was due to the fact that some injuries are sometimes not severe enough in nature to seek medical treatment or receive an alteration in physical activity.[4,13] The NCAA states that an injury has been sustained when an athlete is unable to participate in sport and is excused from at least one practice or game.[3] For the purpose of this study fractures, dislocations, contusions, lacerations, abrasions, and overuse injuries were excluded.

Testing Protocol

Demographic and performance testing was part of pre-participation protocols mandated by the university. Potential risk factors were identified, evaluated, and documented as follows; *Age,* in years, as it was noted in athlete's physical examination forms. *Body Mass Index (BMI)* was calculated as Body Mass (kg)/Height^2 (m) and *Mass Moment of Inertia (MMOI)* was calculated as Mass (kg)*Height (m^2). Athlete *Experience level (EXP)*, in years, that the athlete had finished training with their team as obtained from eligibility through the NCAA. Athlete *Position* was classified as a “back” or a “line” player. Backs included quarterbacks, running back variations, wide receivers, tight ends, cornerbacks, safeties, nickel/dime backs, kickers, and kick-off and punt returners. Line players included all linemen variations, centers, guards, tackles, defensive ends, and linebackers. *Previous Injury History* data was obtained from pre-participation examination records and was defined as an acute core or lower body extremity strain or sprain that warranted evaluation from a Certified Athletic Trainer or health care professional.[1,14] Previously sustained injuries were self-reported by the athletes. Date of injury and severity were not consistently reported so this was not collected for the purposes of this study. It has been shown by previous research that the mere event of a previous injury increases the chances of another injury.[9,15-17] *Neurocognitive Function* was obtained through ImPACT® (Version 3.0, ImPACT® Applications Inc., Pittsburgh, Pennsylvania) administered at the university. If the athlete did not sustain a head injury, the ImPACT® test was not administered again during the season, but in the case of a concussion the most recent baseline data was obtained. From ImPACT® four composite numbers were recorded; *reaction time, processing speed*, *visual memory*, and *verbal memory*.[18] *Muscle and Joint Flexibility Deficit or Abnormality* was collected from orthopedic pre-participation forms after being assessed by a physician. Deficits and abnormalities were recorded as a “yes” or “no” occurrence for each individual based on the limb affected and its corresponding side. *Core Stability and Strength (plank time)* was measured through the front plank to fatigue as administered by the strength and conditioning coaches. Athletes performed the front plank test until form was broken or the athlete decided to quit the test. Core Stability protocols were in accordance with previous research.[19,20] *Bilateral Strength and Power Imbalances* were quantified using the single leg broad jump (SLBJ) for distance as administered by the strength and conditioning coaches. Protocols were consistent with those reported by others.[21,22] The *Functional Movement Screen™ (FMS™)* was utilized to examine if the athletes were able to perform necessary functional patterns for sport (FMS, 1995). Athletes were assessed by the strength and conditioning staff and final score was reported. *Nutritional Status and Deficiencies* were determined from each athlete's blood work that was done at the beginning of the season by a Physician's Assistant. Deficiencies were recorded as a "yes" or "no" occurrence. *Game Exposure* was classified as the occurrence of *"starter status"* in at least one game during the season.[13,14]

Data Analysis

Athletes were dichotomously categorized as injured or uninjured for data analysis. Data was analyzed using SPSS (version 22; SPSS, Inc, Chicago, IL). Receiver operating characteristic (ROC) analyses were used to establish cut points for dichotomization of potential predictive variables which were used do classify athletes as either HRisk or LRisk and the Fisher exact 1-sided test was used to identify injured from uninjured status (1-sided $P < .25$) for each predictor variable. It is common in predictive modeling to use a P-value of .25.[13,14] Backward stepwise logistic regression analysis identified the best combination of predictors and additional ROC analyses identified the best number of positive factors to distinguish athletes who got injured. Another cross tabulation analysis revealed the model's predictive ability. Confidence intervals (CI) were created to assess the magnitude and precision of odd ratio values for the model. Cox Regression, or proportional hazards regression, was used to investigate the effect of several variables upon the occurrence of injury. This was used to quantify the probability for injury occurrence and timing throughout the duration of the football season. Accuracy of these models was assessed by comparison of actual injury incidence through Kaplan Meier Analysis. To further assess any possible interactions between predictive variables further cross tabulation analyses were performed. From this data, five different models were created for this particular cohort of athletes.

For the entire cohort a model was created using a different definition of injury occurrence; *all injuries reported (ALL), limited participation (LP),* or *removed (OUT)* from one or more practice or competitions. Another analysis was limited to second season players to identify possible persisting effects on pre-participation measurements from a previous season injury, which could serve as indicators of elevated risk for a subsequent injury during the second season. Lastly, an analysis was created that encompassed only athletes who were injured in the first season in order to assess potential risk factors that may be persistent over the course of multiple seasons to cause an injury the next season.

RESULTS

The total amount of injuries sustained over the course of two seasons differed greatly by the definition of injury that was utilized for the population; ALL=128(56.88%), LP=99(44%), and OUT=57(25.33%) out of 225 athletes. In year one, 65(57.52%) athletes sustained an ALL injury while 63(56.25%) were injured in year two. 54(47.79%) of athletes sustained an LP injury in year one and 45(40.18%) sustained an LP injury in year two. 32(28.32%) of athletes in year one sustained an OUT injury while only 25(22.32%) of athletes sustained an OUT injury in year two. 83 athletes participated in both seasons. In terms of the 128 total injuries reported that warranted some extent of evaluation, not in regards to modification or treatment following, there were 13(10.16%) foot , 30(23.44%) ankle, 7(5.47%) low leg, 17(13.28%) knee, 49 (38.28%) thigh (including quadriceps, hamstrings, abductors, and adductors), 3(2.34%) glute, 5(3.91%)

low spine, and 4(3.13%) abdomen injuries in the forms of sprains and strains. Entire Cohort means and standard deviations for evaluated risk factors are presented in Table 1.

Entire Cohort Models

Different injury definitions utilized in creation of the entire cohort's prediction model reveals different strength in prediction levels as well as different sets of strong potential predictors for injury incidence.

All Reported Injuries

For ALL injuries, results of univariate analysis of variables that were found to be strong potential predictors of injury ($P<.25$) are shown in Table 2. Logistic regression results identified a short plank time, a slow visual motor speed time (ImPACT®), a high MMOI value, and the occurrence of starter status to be the best set of predictors for injury. Logistic regression results for this injury definition are shown in Table 3. ROC analysis of the 4-factor prediction model identified ≥2 Positive Factors to be the standard for differentiating between injured and uninjured athletes ($P<.001$, OR= 3.2, CI 90% 1.98, 5.20) as presented in Table 4. Injury incidence against different combinations of the predictors is presented in Figure 1. Figures that depict an interaction between variables are paired with a Breslow Day Homogeneity significance level ($P>.1$ suggests no interaction) to assess the level of interaction. The interaction in Figure 1D may suggest that Regardless of MMOI values, athletes who have slow Visual Motor Speed times as measured by ImPACT® may be at greater risk for injury. This may contradict the prediction model that determined that a high MMOI and a slow Visual Motor Speed would predispose the athlete to injury.

The 4-factor prediction model had a high degree of accuracy in determining HRisk athletes and the occurrence of injury (Sens=77.3%). The ALL definition classified 128(56.89%)

athletes as injured and 97(43.11%) not injured. 149 out of 225(66.22%) athletes were labeled as HRisk (≥2 Positive Factors). 99(66.44%) of these athletes were correctly categorized as HRisk while only 50(33.56%) were false positives. The model has less accuracy when correctly assessing LRisk athletes and the avoidance of injury (Spec=48.5%). 76(59.38%) of the 225 athletes were identified as LRisk; 47(61.84%) correctly categorized and 29(38.16%) athletes were incorrectly categorized as false negatives, were missed by the model as HRisk, and sustained an injury (Table 5).

Limited Participation Injuries

For LP injuries, results of univariate analysis of variables that were found to be strong potential predictors of injury (*P*<.25) are shown in Table 6. Logistic regression results identified a slow reaction time (ImPACT®), a high MMOI value, and the occurrence of starter status to be the best set of predictors for injury (Table 3). ROC analysis of the 3-factor prediction model identified ≥1 Positive Factors to be the standard for differentiating between injured and uninjured athletes (*P*<.004, OR= 2.41, CI 90% 1.41, 4.10) (Table 4). Injury incidence against different combinations of the predictors is presented in Figure 2. Figures that depict an interaction between variables are paired with a Breslow Day Homogeneity significance level (*P*>.1 suggests no interaction) to assess the level of interaction.

The 3-factor prediction model had the highest degree of accuracy in terms of HRisk athletes sustaining an injury (Sens=82.8%). The LP definition classified 99(44%) of the 225 athletes as injured and 126(56%) as not injured. 166(73.77%) out of 225 athletes were labeled as HRisk (≥1 Positive Factors). 82 (49.4%) of the identified 166 athletes were correctly categorized as HRisk while 84(50.6%) were false positives. This model did not have good accuracy in determining LRisk athletes and their ability to avoid an injury (Spec=33.3%). 59(26.22%) of the 225 athletes were identified as LRisk; 42(71.19%) of the 59 athletes correctly categorized and 17(28.81%) athletes were incorrectly categorized as false negatives, were missed by the model as HRisk, and sustained an injury (Table 5).

Removal from At Least One Session Injuries

For OUT injuries, results of univariate analysis of variables that were found to be strong potential predictors of injury (*P*<.25) are shown in Table 7. Logistic regression results identified a high MMOI value, an appearance of a flexibility deficit, and the occurrence of starter status to be the best set of predictors for injury (Table 3). ROC analysis of the 3-factor prediction model identified ≥2 Positive Factors to be the standard for differentiating between injured and uninjured athletes (*P*<.012, OR=2.25, CI 90% 1.27, 4.00) as presented in Table 4. Injury incidence against different combinations of the predictors is presented in Figure 3. Figures that depict an interaction between variables are paired with a Breslow Day Homogeneity significance level (*P*>.1 suggests no interaction) to assess the level of interaction.

The 3-factor prediction model had the lowest degree of accuracy when determining HRisk athlete's incidence of injury (Sens=75.4%). The OUT definition classified 55 athletes as injured and 168 not injured. 140(62.22%) out of 225 athletes were labeled as HRisk (≥2 Positive Factors). 43(30.71%) of the 140 were correctly categorized as HRisk while 97(69.29%) were false positives. This model has less accuracy when determining the ability of LRisk athletes to avoid injury incidence (Spec=42.3%). 85(37.77%) of the 225 athletes were identified as LRisk; 71(8.53%) of the 85 athletes were correctly categorized and 14(16.47%) athletes were incorrectly categorized as false negatives, were missed by the model as HRisk, and sustained an injury (Table 5).

Previous Injury Effects on Injury Incidence

Limiting or modifying athlete participation in sport is the most utilized classification of injured status in athletics and in predictive modeling.[4,13,14,24] Results of univariate analysis of variables that were found to be strong potential predictors for subsequent injury due to previous season injury occurrence ($P<.25$) are shown in Table 8. Logistic regression results identified those athletes in Year 2 that had a previous injury history in Year 1to have high levels of experience, a large MMOI value, other previous injury history, and a slow visual motor speed (Table 3). ROC analysis of the 4-factor prediction model identified = 4 Positive Factors to be the standard for differentiating between injured and uninjured athletes ($P<.001$, OR= 8.61, CI 90% 2.00, 18.53) as presented in Table 4. Injury incidence against different combinations of the predictors is presented in Figure 4. Figures that depict an interaction between variables are paired with a Breslow Day Homogeneity significance level ($P\geq .1$ suggests no interaction) to assess the level of interaction.

The 4-factor prediction model had low degree of accuracy in correctly assessing HRisk athlete injury incidence (Sens=58.5%). This model classified 41(36.61%) of the 112 athletes as previously injured the season prior and 71(63.4%) as not injured. 34(30.36%) out of 112 athletes in year 2 were labeled as HRisk (=4 Positive Factors). 24(70.59%) of these 34 were correctly categorized as HRisk while 10(29.41%) were false positives. On the other hand, the model has very high accuracy when correctly assessing LRisk athlete’s ability to avoid injury (Spec=85.9%). 78(69.64%) of the 112 athletes were identified as LRisk; 61(78.21%) of these 78 correctly categorized and 17(21.17%) athletes were incorrectly categorized as false negatives, were missed by the model as HRisk, and sustained an injury (Table 5).

Only Athletes with LP injury in Year 1 and injured status in Year 2 Model

For only the athletes who sustained LP injuries in year 1, results of univariate analysis of variables that were found to be strong potential predictors of subsequent LP injuries in Year 2 ($P<.25$) are shown in Table 9. Logistic regression results identified a slow reaction time (ImPACT®), a low verbal memory score (ImPACT®), a short duration plank time, previous injury history, and the occurrence of starter status to be the best set of predictors for injury subsequent injury following Year 1(Table 3). ROC analysis of the 4-factor prediction model identified ≥3 Positive Factors to be the standard for differentiating between injured and uninjured athletes ($P<.011$, OR= 8.40, CI 90% 2.00, 35.70) as presented in Table 4. Injury incidence against different combinations of the predictors is presented in Figure 3. Figures that depict an interaction between variables are paired with a Breslow Day Homogeneity significance level ($P>.1$ suggests no interaction) to assess the level of interaction.

The 4-factor prediction model had the lowest degree of accuracy when correctly assessing HRisk athlete incidence of injury during the season (Sens=44.4%). Out of the 83 athletes that participated in both seasons, 41(49.4%) of the athletes who sustained a LP injury in year 1. This model classified 18 of those 41(43.9%) athletes as injured and 23(56.1%) not injured. 10(24.39%) of the 41 athletes were labeled as HRisk (≥3Positive Factors). 8(80%) of these 10 were correctly categorized as HRisk while 2(20%) were false positives. On the other hand, the model has very high accuracy when correctly determining LRisk athlete ability to avoid injury (Spec=91.3%). 31(75.61%) of the 41 athletes were identified as LRisk; 21(67.74%) of the 31 correctly categorized and 10(32.26%) athletes were incorrectly categorized as false negatives, were missed by the model as HRisk, and sustained an injury (Table 5).

Cumulative Hazard and Model Accuracy

With the creation of prediction models, professionals seek to determine when an injurious event will occur if no attempt to modify risk factors is taken.[13,14] Through cumulative hazard that is predicted by cox regression analysis, professionals can seek to estimate when injuries are more likely to occur when an athlete meets the predictive criteria compared to an athlete who does not meet the criteria. In order to establish accuracy of these models, a Kaplin Meier analysis can then be paired to show actual incidence of injury over time. [13,14] Cumulative hazard analyses that match the Kaplin Meier analysis are more accurate in determining the amount of days athletes can avoid injury occurrence and the cumulative risk associated.

Cumulative hazard analyses are depicted in Table 4 and Figure 6. It appears that while the OUT definition of injury has the greatest injury incidence, that the LP definition is the most accurate when compared to the actual cumulative hazard risk for injury. Additionally the hazard ratio for the LP definition is the greatest (ALL HR=2.13; CI (1.50, 3.02), LP HR= 2.20; CI (1.42, 3.42), OUT HR= 2.18; CI (1.31, 3.61)) (Table 4). Additionally when examining the model that includes only athletes in year 2 and previous injury occurrence the season before, the prediction models cumulative hazard analysis is nearly identical to actual injury avoidance and allows professionals to see that athletes that meet the predictive criteria are at risk for injury by over three times more than people who do not meet the criteria at any point during the season if no preventative measures are taken (Table 4, Figure 6). Conversely, the cumulative hazard model looking at athletes injured according to the LP definition during the first year depicts a model that is slightly different, often identifying athletes at a greater cumulative risk who meet the predictive criteria then the actual injury incidence. While incorrect, it may allow professionals to overestimate the risk of injury occurrence over the course of a season but still may encourage extra preventative measures especially since this model does depict the largest hazard ratio (HR=3.747; CI (1.71,8.21)) (Table 4, Figure 6).

DISCUSSION

Today, some studies focus on the prediction for a certain injury, such as ankle sprain occurrence in high school football athletes[9], while others aim to predict the occurrence of any acute upper and lower body injury in sport. Wilkerson et al. in 2012[14] took various preseason measurements in college Division 1 football athletes and documented game exposure as well as injury incidence during the football season. A 4-FM consisting of high game exposure, low trunk flexion hold time, high Oswestry Disability Index score, and a short wall sit hold time, was created that placed athletes over 10 times more likely to sustain an injury with ≥3 positive factors then an athlete who had ≤2 positive factors. This model is in support if the results of this study where regardless of which definition was used to determine injury incidence similar models were able to be created that encompassed similar risk factor variables such as game exposure, poor core stability, neurocognitive abilities, and body composition. Further, this study allowed for separate analysis over multiple years of injury incidence and allows professionals to look at risk factors that may be indicative of consecutive injuries.

Many factors such as poor core stability and endurance, poor neurocognitive function, previous injury history, high competition exposure, and flexibility abnormalities have previously been linked to increased injury incidence.[9, 14, 15, 24, 37, 53] Lower extremity sprains and strains have been estimated to be as high as 6.8 injuries per 1000 exposures in Division 1 sports.[10] It is clear that by first identifying the incidence of injury and common factors, introducing measures to reduce risk, and then reevaluating measures to break the injury cycle is the best course.[4]

There are many definitions of “sports injury” which can make predictive modeling difficult. The NCAA states that an injury has been sustained when an athlete is unable to participate in sport and must completely miss at least one practice or game.[3] Conversely, many athletes approach the medical staff with an injury that warrants an evaluation but does not result in missed or modified practice.[14] Though not considered “injured” by the NCAA, the athlete may suffer from adverse effects. Furthermore, it is widely accepted that an injury is sustained when an athlete is not able to fully participate in sport warranting an evaluation and requires medical treatment until full participation can be resumed, labeling the athlete as “limited participation” not “out”.[1]

Definition Variability

This study exemplified the variation of predictive variables and model subsequent strength when utilizing different definitions of injury. When examining the entire cohort over the span of two seasons, the broadest definition of injury incidence, ANY, identified the highest injury occurrence (128/225; 56.88%), LP injuries, the most commonly used definition of injury following (99/225; 44%), and the strictest definition, OUT, labeling less ten half of ANY injuries reported as injuries (57/225; 25.33%) (Table 5). While these models had very high accuracy when determining injury incidence among HRisk athletes, the most commonly used definition of LP has the highest accuracy (ANY= 77.3%; $P<.001$, LP= 82.8%; P=.004, OUT= 75.4%; $P=.012$). However, it should be noted that none of these models are superior when it comes to correctly assessing the ability for LRisk athletes to avoid injury (ANY= 48.5%; $P<.001$, LP= 33.3%; $P=.004$, OUT= 42.3%; $P=.012$) (Table 4). This results in extreme numbers of athletes completing potential unnecessary preventative measures but ensures that athletes who are more susceptible to injury are correctly labeled as HRisk.[4,12]

Similarly, the definition of injury also changes the subsequent risk, odds ratios, associated with sustaining an injury if the clinical prediction criteria is met for the specific model (ANY OR= 3.21; CI (1.98, 5.20), LP OR= 2.41; CI (1.41, 4.10), OUT OR= 2.25; CI (1.27, 4.00) (Table 4). The highest odds ratios being apparent with ANY and LP definitions states that athletes labeled as HRisk through these models puts them at max around 5 times more likely to sustain an injury then athletes who are labelled as LRisk for injury. This suggests that with these definitions of injury, medical professionals can better encompass different severities of injuries that are reported, evaluated, and corrective procedures initiated; not wait for injuries that cause athletes to be removed from their sport.[1,3,14]

Regardless of the definition of injury utilized, there are potential risk factors that are present in multiple models. In all three models the appearance of “starter status” and MMOI, or BMI, were prevalent (Table 3). Wilkerson et al. (2012)[14] found that high game exposure alone put athletes at over 8 times the risk for sustaining an injury which was later confirmed in a refined study published in 2015.[13] It is suggested that athletes who have increased playing time, increase the risk of injury due to repetitive and cumulative trauma from continuous contact, running, and cutting while fatigued from training and other competitions.[5,11,13] BMI intends to provide an indication of how overweight a person is by adjusting body mass for height[9] while MMOI allows professionals to observe the height of an athletes center of gravity (COG).[23] With the increase in BMI and MMOI there is an increase in the risk for musculoskeletal injury, either directly as a result of greater joint loading or indirectly through its association with the possibility of poor physical conditioning, and a decreased ability to effectively and rapidly change momentum. [9,23,24] While starter status is not something that can be modified, BMI and MMOI can be slightly affected overtime.

In both the ANY and LP models, suboptimal neurocognitive ability is identified as a risk factor (ANY= slow visual motor speed, LP= slow reaction time) (Table 3). It is becoming more common for professionals to evaluate athlete's processing speed, working memory, attention, and concentration through the ImPACT® test since it has been shown to be a reliable method for examining neurocognitive performance.[25,26] Deficiencies in reaction time and processing speed may indicate diminished ability of an athlete to maintain neuromuscular control.[27] The presence of these variables is supported by Wilkerson et al. (2012)[14] who found that a reaction time of less than 0.545 seconds had a 2-fold increased risk for a lower extremity injury.

Despite previous literature, the ANY model was the only one to identify short plank time hold as a potential risk factor. Suboptimal endurance of the core muscles has been associated with impaired neuromuscular control of the body's center of mass and coordination of lower extremity muscles, as well as the elevated risk for lower extremity injuries.[13,14,28-30] The lack of significance in this study may be deemed to the different ways of measuring core strength and stability such as the plank hold versus the trunk flexion hold[14,31,32] Likewise, flexibility deficits were flagged as a potential factor only in the OUT model despite previous literature claiming it as one of the most common proposed risk factors for lower extremity injuries.[33-35] Despite this, literature reviews and prospective studies looking at muscle flexibility as an indicator of injury are scarce and incomplete due to the fact that flexibility is sport specific and that muscle tightness or soreness may alter measurements throughout the season making flexibility hard to assess accurately.[33,34]

Previous Injury Effect on Current Demographics and Performance

In collegiate football, athletes often spend 4+ years on their respective football team. Turbeville et al. (2013)[11] found that an increase in football experience was associated with up to

60% increase in injury risk for every one year. This suggests that as athletes spend more time playing a sport, they are more likely to get an injury. A question is then posed; “Does current demographics and performance measures correlate to injured status during the season prior?” If a model identifies current components that are common amongst those that are injured the year before, then medical professionals could take the step to modify them before injury occurs.[4,13]

This study assessed the 112 second year athletes and compared them to injury occurrence during the year prior. Due to the fact that the LP definition of injury is most widely accepted, athletes who sustained an injury that received some kind of modification to their participation were classified as “injured”. [1,4] This model identified 41 previous season injuries. While having lower accuracy in correctly assessing HRisk athlete’s injury incidence (Sens=58.5%) the model was very accurate in determining of the ability of LRisk athletes to avoid injury (Spec=85.9%) (Table 3). This suggests that medical professionals can ensure that athletes who are marked as LRisk are in fact LRisk for injury, while those who are marked HRisk may not actually be at risk but can still benefit from extra preventative measure work.[4,13] Further, this model marks athletes who are labeled as HRisk with an OR of 8.61 (*P*<.001; CI 90% 4.00, 18.53).

The 4-FM identified high experience, high MMOI values, previous injury history, and slow visual motor speed as risk factors current risk factors that the athletes shared. Since it has been suggested that increased experience increases injury risk as well as having, high MMOI values, and slow visual motor speed, those risk factors are in line not only with previous models in this study but also in previous literature.[9,14,22-26] For this model, 100% of the athletes identified with a previous season injury, also had a previous injury history from years prior to the previous season injury with an OR of 13.02 (CI 2.65, 36.56) (Table 3). Fousekis et al. (2012)[16] found that athletes who have a previous injury history may have asymmetries in neuromuscular coordination, strength, and reaction time as well as other components required for performance. This may result from athletes returning to sport before impairments are fully resolved causing the athlete developing some form of compensation.[16,36,37] It may become apparent that lingering previous injuries and acquired abnormalities involving neuromechanical and neuromuscular deficits may have a large effect on other factors and that may increase injury incidence. There is a need for screening protocols that identify incomplete physical, mechanical, neurocognitive, and proprioceptive healing as well as any other athlete characteristics that may exacerbate the persisting effects of injury.

Injuries Occurring Over Multiple Years

Lastly, a model was created that assessed athletes that sustained an LP injury in year 1 against the incidence of sustaining another LP injury in year 2. This model allows medical professionals to identify the risk factors that athletes injured for multiple years in succession share in order to identify which factors need additional attention to decrease injury incidence. [4,13] This model identified 41 athletes who sustained an LP injury in year 1, 18 of which sustained another LP injury in year 2. While this model was not very accurate in determining HRisk athletes and the incidence of subsequent injury (Sens=44.4%) it was the best model for determining LRisk athlete ability to avoid injury (Spec=91.3%) (Table 3). From this model, professionals can ensure that athletes marked as LRisk will in fact be LRisk athletes, enabling professionals to focus their attention on athletes marked as HRisk even if they do not sustain an injury. This model had an OR of 8.40 (*P*<.011; CI (2.00, 35.70) (Table 3).

The 4-FM identified slow reaction time, low verbal memory score, short plank time, the occurrence of starter status, and previous injury history as risk factors for subsequent injuries which has been supported in previous research.[9,13,14,22,23,25,26,28,29]For this model, 100% of the athletes identified also had a previous injury history from years prior to the previous season injury (Table 3). Verbal memory score is a component of neurocognitive ability that is assessed via ImPACT®. Previously, athletes with previous ACL injuries were found to have lower visual and verbal memory scores. Athletes with poor memory skills may be likely to make judgment errors or exhibit loss of coordination during competition which may result in injury.[27,38] Since all the athletes exhibited a previous injury history, it is possible that asymmetries in neuromuscular coordination, strength, memory, and reaction time resulted. This may result from athletes returning to sport before fully healed and thus always playing with some form of compensation or from a lack of practice.[16,36,37] If these modifiable factors are targeted, athletes may be able to better avoid injury.

Limitations

The biggest limitation to prediction models is that there are variations in ways that variables can be assessed and that there is cohort variability from one year to the next.[14] In terms of an athletic cohort, teams will change each year with a change in training techniques and staff employment. Further, the techniques for assessing the same component of the athlete's make up may also vary.[16] It is widely accepted that intrinsic factors that make up an athlete's physical being change continuously, making them more susceptible to injuries as certain factors become apparent.[4,13] Additionally, some factors are modifiable over time as prediction studies are utilized to determine at risk athletes; neurocognitive abilities, flexibility deficits, core strength, and functional movement patterns.[4,5,13-16]

The reliability of associations derived from cohort studies is highly dependent on the number of injured cases for this study. It has been suggested that in order to find significance in a cohort study approach that researchers observe and estimate 20 to 50 injury cases with at least

200 participants.[6] That criteria was not met with all of the models in this study. If there are not enough injured cases then the data may not be able to be replicated with a larger or different group of athletes.

For future studies, much larger data sets are necessary to create reliable injury-prediction models for different ages, genders, sports, positions, and specific injuries. Research needs to be done on cumulative season effect on injury and factors that athletes have in common. Another limitation was the possibility that important predictors of college football injury risk were not included or that factors included may be performed another way in order to achieve a better outcome. In addition, previous season data is often not available or reliable. For example, there was a lack of previous injury history data and data in regards to injured status during “year 0” and for incoming freshman due to a lack of documentation. Finally, researchers and clinicians should seek to evaluate different operational definitions of injury as there are different definitions that can completely change results in predictive modeling.

Conclusions

Different definitions of injury can drastically change the components that make up a prediction model when assessing injury incidence during a season. While the definition of ANY injury will encompass all injuries regardless of severity, there are often injuries reported that are not substantial in nature and prediction models created may incorrectly determine which athletes are high risk for injury. Conversely, the OUT definition of injury is very strict and only takes into account injuries that remove the athlete from practice while in reality most injuries only limit participation. The LP definition of injury when creating prediction models may be the best balance in correctly determining injury incidence for HRisk athletes and avoidance of injury in LRisk athletes and the resulting model most closely resembled cumulative injury risk over the course of a season than any of the other definitions. Additionally, injury the previous season may negatively influence intrinsic factors, such as MMOI and visual motor speed (neurocognitive abilities), that may otherwise be stable if the injury is handled properly and all abnormalities are addressed during rehabilitation and prior to return to play. Lastly, it is likely that there are common sets of intrinsic risk factors (reaction time, verbal memory ability, and core strength and stability) that athletes injured multiple years in succession share that could be rectified over time to decrease injury incidence in NCAA Division 1 collegiate football teams.

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FIGURES AND TABLES

Table 1. Cohort Demographics for Dichotomized Variables

Variable	Mean	Standard Deviation	Count: Above Mean/ Yes	Count: Below Mean/No
Age	19.68 Years	± 1.41	114	111
BMI	30.40 kg/m^2	± 5.18	93	132
MMOI	382.62 kg*m^2	± 100.42	90	135
Experience	1.35 Years	± 1.17	91	134
Position			Backs n= 133	Line n= 92
Previous Injury			184	41
Flexibility Deficit			107	118
Nutrition Deficit			141	84
Reaction Time	0.63 sec.	± 0.10	97	128
Visual Motor Speed	34.50 sec.	± 7.68	111	114
Visual Memory	72.64	± 13.80	116	109
Verbal Memory	82.92	± 11.95	131	94
FMS	14.1	± 1.73	101	124
Single Leg Broad Jump Distance Deficit			216	9
Single Leg Broad Jump Deficit Amount	4.15 inches	± 2.35	118	107
Plank Time	152 sec.	± 69.76	84	141
Starter Status			83	142

Table 2. Entire Cohort (ANY injury) Results of Cross-Tabulation Analysis of Dichotomized Variables

Variable	Cutpoint	Sensitivity	Specificity	P value[a]	Odds Ratio (90% CI)
MMOI[b]	≥ 314.705 kg*m^2	75.00%	38.10%	0.03	1.85 (1.04,3.28)
Visual Motor Speed	≥ 28.265 sec.	27.30%	87.60%	<0.01	2.67 (1.30,5.47)
Plank Time	≥ 157 sec.	68.00%	40.20%	0.13	1.43 (0.82,2.47)
Starter Status	Yes	46.10%	75.30%	<0.01	2.60 (1.46,4.63)

[a] Fishers Exact Test One-sided P-Value

[b] Estimated Mass Moment of Inertia

Table 3. Logistic Regression Results for Determined Models

Injury Definition/Model	Components	Adjusted Odds Ratio (CI 90%)	Nagelkerke R	Hosmer & Lemeshow Significance
Any Injury Reported (ANY)	Plank Time ≤ 157 sec.	1.41 (.86,2.34)	0.13	0.82
4 Factor	Visual Motor Speed ≥ 28.265 sec.	2.56 (1.36,4.79)		
	MMOI ≥ 314.705 kg*m^2	1.55 (0.93,2.57)		
	Starter Status	2.86 (1.72,4.75)		
Limited Participation (LP)	Reaction Time ≥0.695 sec.	1.81 (1.06,3.09)	0.05	0.70
3 Factor	BMI ≥ 30.045 kg/m^2	1.62 (1.03,2.54)		
	Starter Status	1.62 (1.01,2.58)		
Removed (OUT)	MMOI ≥ 279.38 kg*m^2	2.04 (0.78,5.33)	0.06	0.70
3 Factor	Starter Status	2.01 (1.19,3.39)		
	Flexibility Deficit	1.82 (1.08,3.08)		
Year 2 v. Previous Year Injury[a]	Experience ≥ 1 Year	14.90 (4.03,55.05)	0.44	0.98
(Y2vPrevinj)4 Factor	MMOI ≥ 333.9 kg*m^2	3.20 (1.42,7.19)		
	Previous Injury	13.02 (2.65,36.56)		
	Visual Motor Speed ≤ 26.71 sec.	2.17 (0.74,6.35)		
Athletes Injured Year 1 Only[a]	Reaction Time ≥ 0.56 sec.	7.72 (1.26,47.18)	0.29	0.98
(InjY1) 4 Factor	Verbal Memory Score ≤ 89	3.12 (0.77,13.28)		
	Plank Time ≤ 122.50 sec.	3.60 (0.45,28.60)		
	Starter Status	3.63 (0.94, 14.06)		

[a] 100% Previous Injury History for entire population identified

Table 4. Accuracy Statistics for Prediction Models

Injury Definition	Model	Clinical Prediction Criteria	*P*-Value[a]	Sensitivity	Specificity	Odds Ratio (CI 90%)	Hazard Ratio (CI 90%)
ANY	4 Factor-BS	≥ 2 Positive Factors	<.001	77.30%	48.50%	3.21 (1.98,5.20)	2.13 (1.50,3.02)
LP	3 Factor- BS	≥ 1 Positive Factors	.004	82.80%	33.30%	2.41 (1.41, 4.1)	2.20 (1.42,3.42)
	4 Factor- InjY1[b]	≥ 3 Positive Factors	.011	44.40%	91.30%	8.40 (2.0,35.70)	3.75 (1.71,8.21)
	4 Factor-Y2vPrevinj[b]	All 4 Positive Factors	<.001	58.50%	85.90%	8.61 (4.0, 18.53)	3.23 (1.92,5.44)
OUT	3 Factor- BS	≥ 2 Positive Factors	.012	75.40%	42.30%	2.25 (1.27, 4.0)	2.18 (1.31,3.61)

[a] Fisher exact 1-sided P Value

[b] 100% Previous Injury History for entire population identified

Table 5. Results of Cross-Tabulation Analysis of Final Prediction Models

Injury Def./ Model	Status	Clinical Prediction Criteria	Injury	No Injury	Total
ANY	**High Risk**	**≥ 2 Positive Factors**	99	50	149
4 Factor	**Low Risk**	**≤ 1 Positive Factor**	29	47	76
	Total		128	97	225
LP	**High Risk**	**≥ 1 Positive Factors**	82	84	166
3 Factor	**Low Risk**	**0 Positive Factors**	17	42	59
	Total		99	126	225
OUT	**High Risk**	**≥ 2 Positive Factors**	43	97	140
3 Factor	**Low Risk**	**≤ 1 Positive Factor**	14	71	85
	Total		57	168	225
Y2vPrevinj	**High Risk**	**≥ 4 Positive Factors**	24	10	34
4 Factor	**Low Risk**	**≤ 3 Positive Factors**	17	61	78
	Total		41	71	112
InjY1	**High Risk**	**≥ 3 Positive Factors**	8	2	10
4 Factor	**Low Risk**	**≤ 2 Positive Factor**	10	21	31
	Total		18	23	41

Table 6. Entire Cohort (LP injury) Results of Cross-Tabulation Analysis of Dichotomized Variables

Variable	Cut-point	Sensitivity	Specificity	*P*-Value[a]	Odds Ratio (CI 90%)
BMI[b]	≥ 30.045 kg/m^2	51.50%	60.30%	0.05	1.62 (0.95, 2.75)
Reaction Time	≥ 0.695 sec.	28.30%	81.70%	0.05	1.77 (0.94,3.31)
Starter Status	Yes	42.40%	67.50%	0.08	1.53 (0.89,2.64)

[a] Fishers Exact Test One-sided *P*-Value

[b] Estimated Body Mass Index

Table 7. Entire Cohort (OUT injury) Results of Cross-Tabulation Analysis of Dichotomized Variables

Variable	Cut-point	Sensitivity	Specificity	*P*-Value[a]	Odds Ratio (CI 90%)
MMOI[b]	≥ 279.38 kg*m^2	93.00%	13.10%	0.16	2.00 (0.66, 6.06)
Flexibility Deficit	Yes	56.10%	55.40%	0.10	1.59 (0.87,2.91)
Starter Status	Yes	59.60%	36.30%	0.35	1.84 (1.01, 3.66)

[a] Fishers Exact Test One-sided *P*-Value

[b] Estimated Mass Moment of Inertia

Table 8. Year 2 Athletes against Previous Season Injury (LP) Results of Cross-Tabulation Analysis of Dichotomized Variables

Variable	Cut-point	Sensitivity	Specificity	*P*-Value[a]	Odds Ratio (CI 90%)
MMOI[b]	≥ 333.90 kg*m^2	68.00%	44.80%	0.18	1.73 (0.67, 4.42)
Experience	≥ 1 Year	96.00%	34.50%	<0.01	12.63 (1.63, 97.99)
Previous Injury	Yes	100.00%	20.70%	0.01	1.36 (1.21, 1.54)
Visual Motor Speed	≥ 41.86 sec.	20.00%	89.70%	0.17	2.17 (0.65,7.18)

[a] Fishers Exact Test One-sided *P*-Value

[b] Estimated Mass Moment of Inertia

Table 9. Athletes Injured (LP) in Year 1 Only Results of Cross-Tabulation Analysis of Dichotomized Variables

Variable	Cut-point	Sensitivity	Specificity	*P*-Value[a]	Odds Ratio (CI 90%)
Reaction Time	≥ 0.56 sec.	88.90%	34.80%	0.08	4.27 (0.78, 23.40)
Verbal Memory	≤ 89	77.80%	43.50%	0.14	2.69 (0.68,10.74)
Plank Time	≤ 122.50 sec.	27.80%	95.70%	0.05	8.46 (0.89, 80.59)
Starter Status	Yes	55.60%	56.50%	0.33	1.63 (0.47, 5.63)

[a] Fishers Exact Test One-sided *P*-Value

*****100% Previous Injury History for entire population identified

Figure 1. Entire Cohort (ANY) Lower extremity sprain and strain incidence for pairs of dichotomized variables. Independent variables are designated as both high or low and positive (+) or negative (-) based on cut points derived from ROC analysis. Each possible combination is presented. A: Starter Status vs. Plank Time; B: Starter vs. MMOI; C: Starter vs. Visual Motor Speed; D: MMOI vs. Visual Motor Speed; E: Plank Time vs. Visual Motor Speed

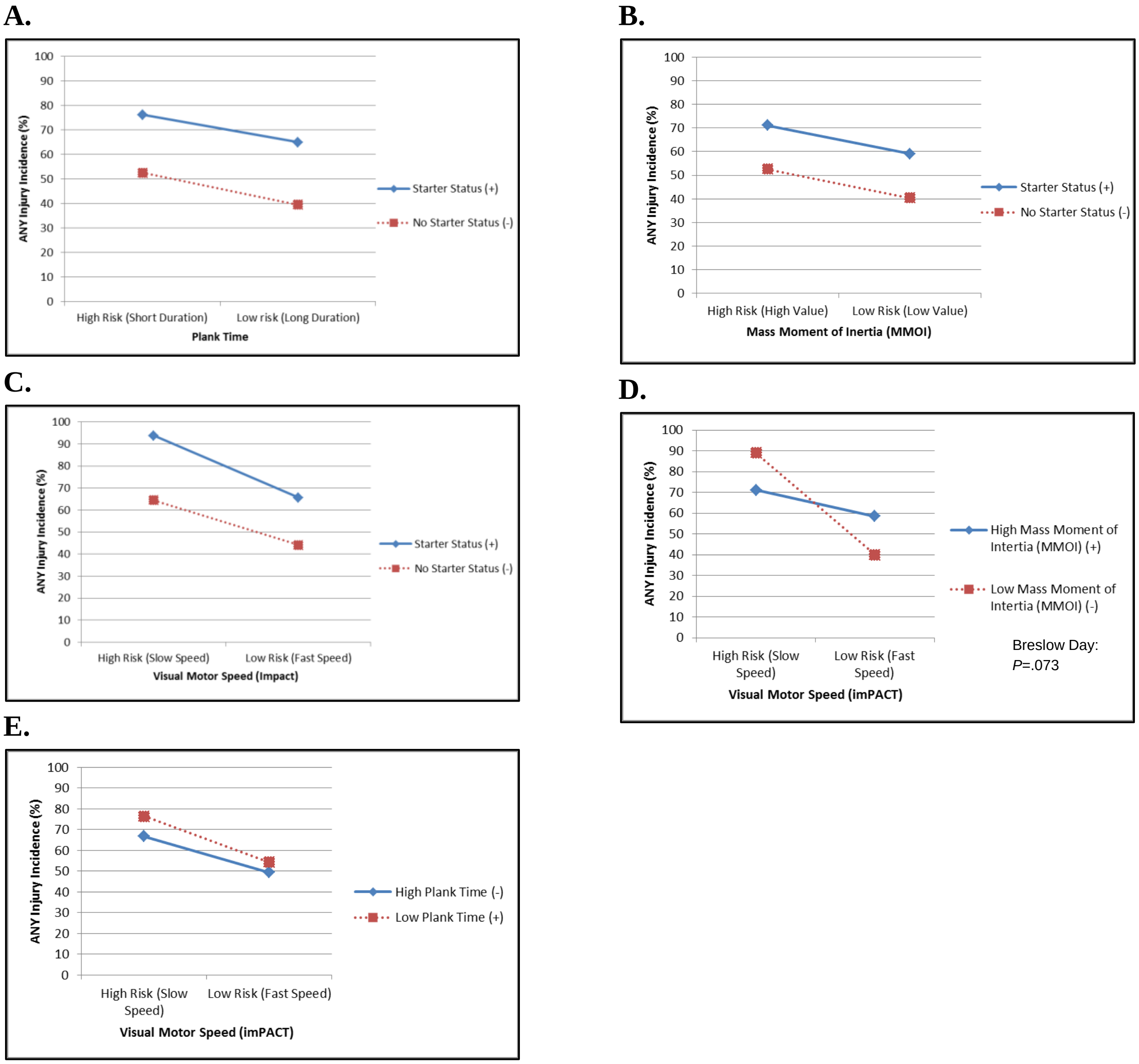


Figure 2. Entire Cohort (LP) Lower extremity sprain and strain incidence for pairs of dichotomized variables. A: Starter vs. Reaction Time; B: Starter vs. BMI; C: Reaction Time vs. BMI

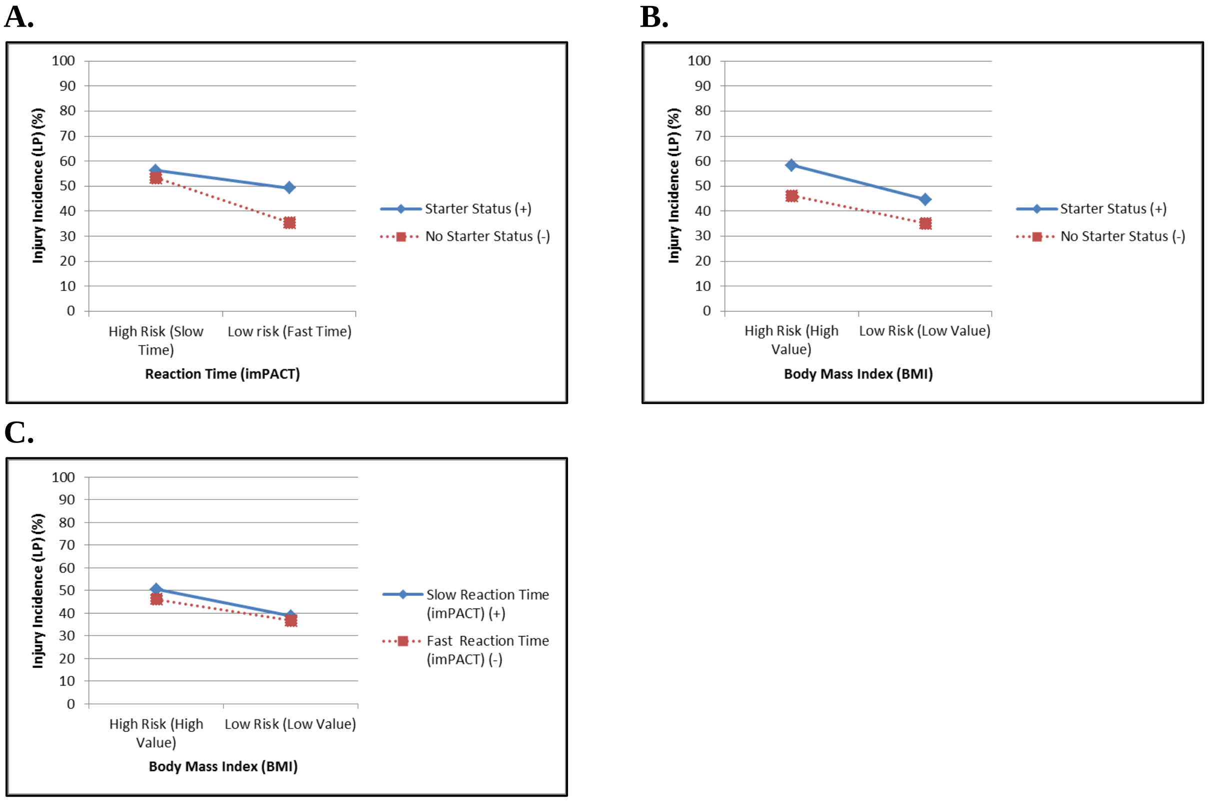


Figure 3. Entire Cohort (OUT) Lower extremity sprain and strain incidence for pairs of dichotomized variables. A: Starter vs. MMOI; B: Starter vs. Flexibility Deficit; C: MMOI vs. Flexibility Deficit

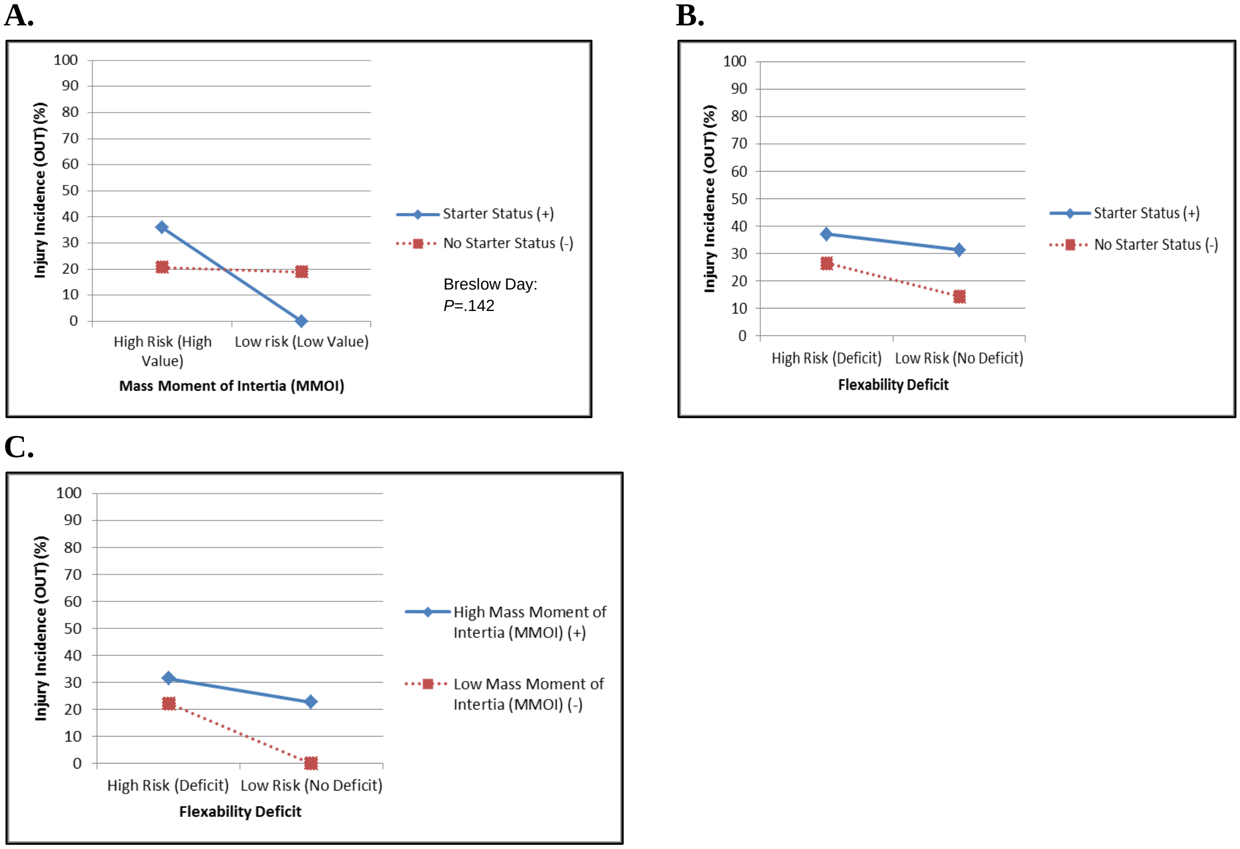


Figure 4. Year 2 Athletes against Previous Season Injury (LP) Lower extremity sprain and strain incidence for pairs of dichotomized variables. A: MMOI vs Previous Injury History; B: MMOI vs. College Experience; C: MMOI vs. Visual Motor Speed; D: College Experience vs. Previous Injury History; E: College Experience vs. Visual Motor Speed; F: Visual Motor Speed vs. Previous Injury History

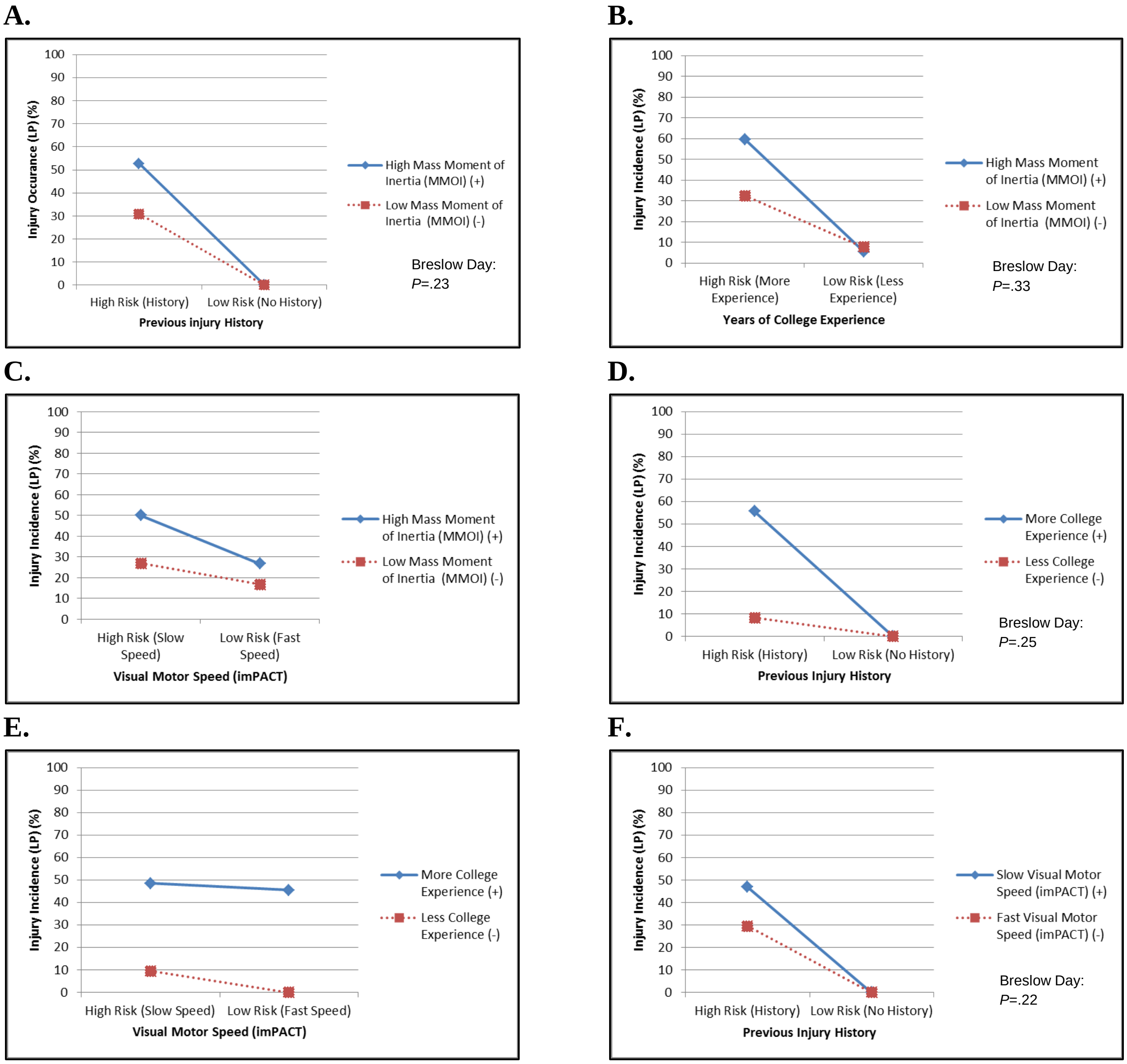


Figure 5. Athletes Injured (LP) in Year 1 Lower extremity sprain and strain incidence for pairs of dichotomized variables. A: Starter vs. Reaction Time; B: Starter vs. Verbal Memory Score; C: Starter vs. Plank Time; D: Plank Time vs. Verbal Memory Score; E: Reaction Time vs. Verbal Memory Score; F: Reaction Time vs. Plank Time.

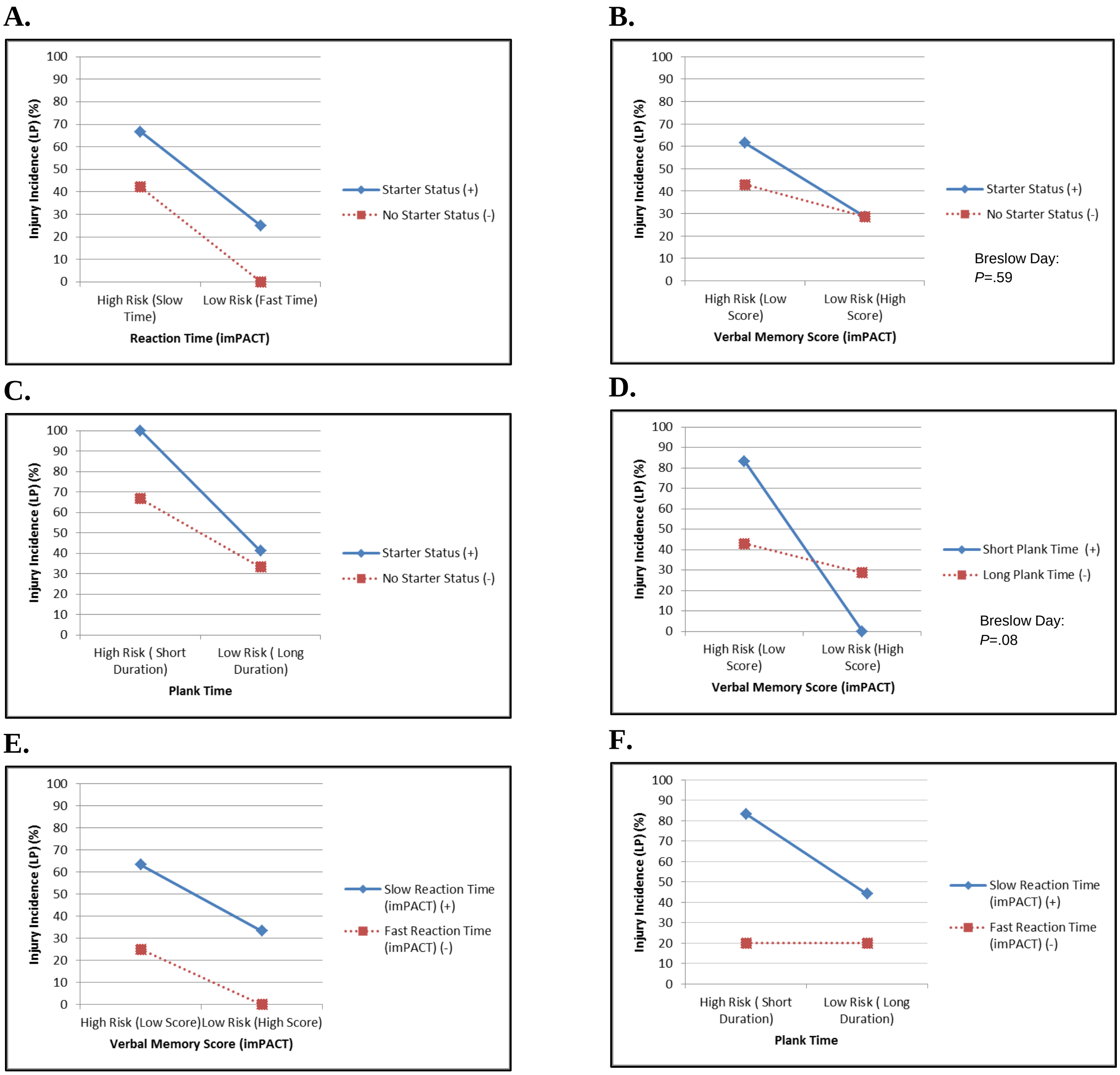
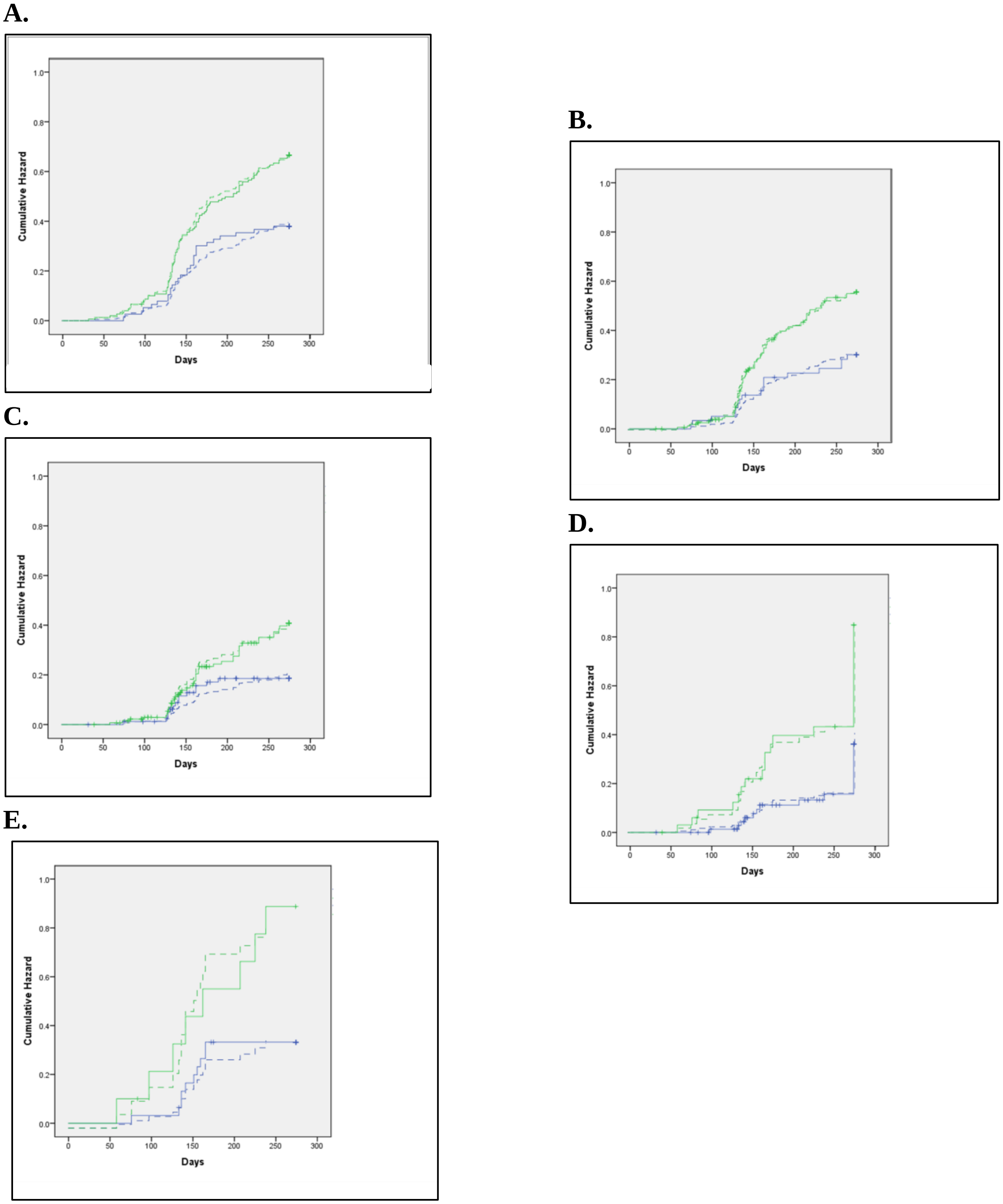


Figure 6. Cox Regression (dotted line) equation and Kaplin Meier (solid line) analysis prediction of injury hazard for high-risk (green line) versus low-risk (blue line) status for each predictive model. A: Entire Cohort ALL, B: Entire Cohort LP, C: Entire Cohort OUT, D: Year two athletes and previous injury LP, E: Athletes injured year one and year two injury incidence LP.



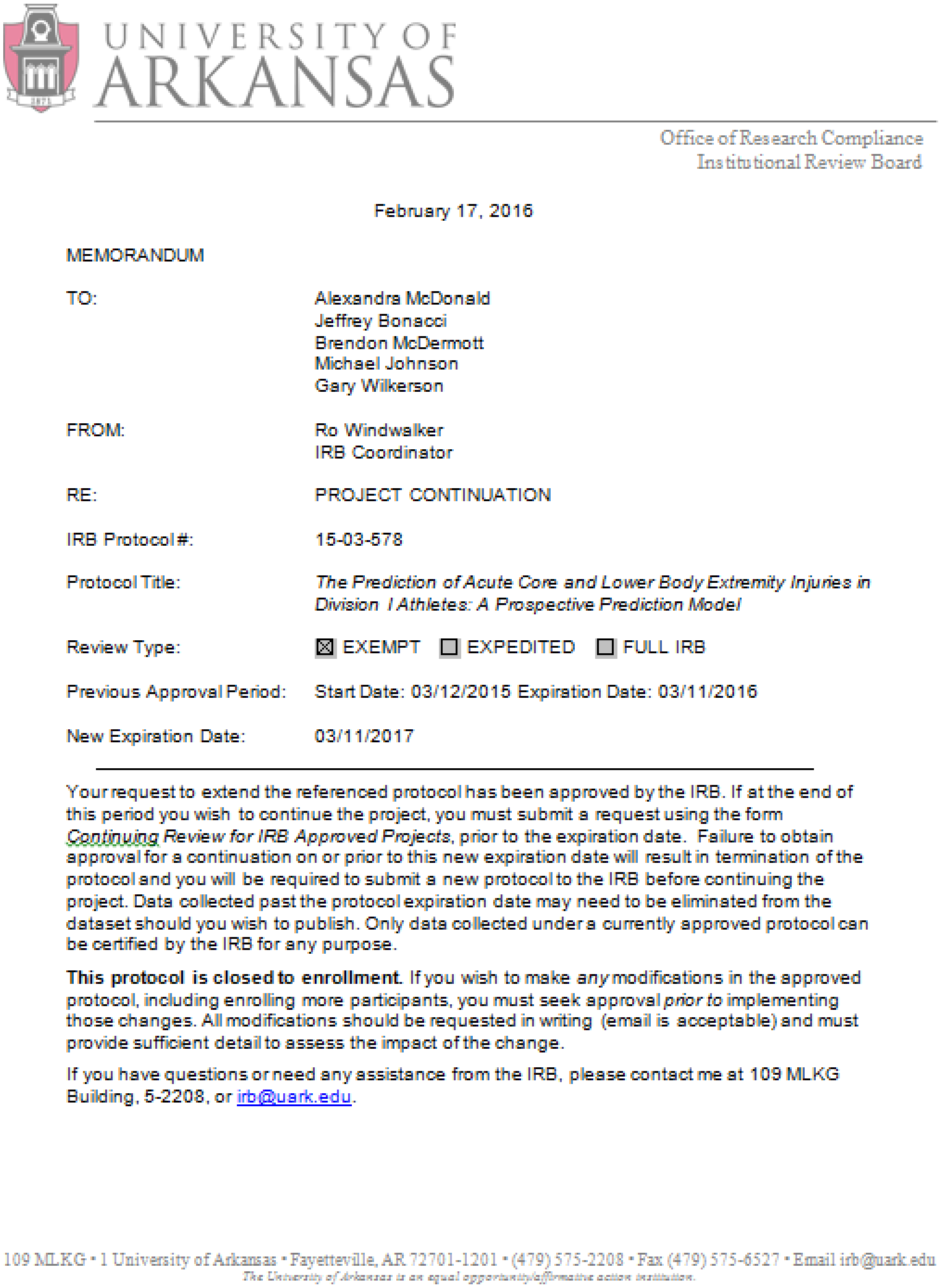
V. Discussion and Conclusion

The purpose of this study was to assess the value of different variables that have been shown to be potential risk factors for core and lower extremity sprains and strains in collegiate football players. A secondary purpose was to identify the strongest set of predictors for a cohort of athletes to categorize these athletes as either high risk (HRisk) or low risk (LRisk) for injury occurrence which could be used as a way to identify those susceptible to injury over the course of a season and the tertiary purpose was to assess whether definition of injury occurrence changes the set of potential predictive factors and the risk of injury occurrence.

Different definitions of injury can drastically change the components that make up a prediction model when assessing injury incidence during a season. While the definition of ANY injury will encompass all injuries regardless of severity, there are often injuries reported that are not substantial in nature and prediction models created may incorrectly determine which athletes are high risk for injury. Conversely, the OUT definition of injury is very strict and only takes into account injuries that remove the athlete from practice while in reality most injuries only limit participation. The LP definition of injury when creating prediction models may be the best balance in determining athletes that are high and low risk and the resulting model most closely resembled cumulative injury risk over the course of a season than any of the other definitions. Additionally, injury the previous season may negatively influence intrinsic factors, such as MMOI and visual motor speed (neurocognitive abilities), that may otherwise be stable if the injury is handled properly and all abnormalities are addressed during rehabilitation and prior to return to play. Lastly, it is likely that there are common sets of intrinsic risk factors (reaction time, verbal memory ability, and core strength and stability) that athletes injured multiple years in succession share that could be rectified over time to decrease injury incidence in NCAA Division 1 collegiate football teams.

VI. Appendix

IRB Approval Letter



UNIVERSITY OF ARKANSAS

Office of Research Compliance
Institutional Review Board

February 17, 2016

MEMORANDUM

TO:	Alexandra McDonald Jeffrey Bonacci Brendon McDermott Michael Johnson Gary Wilkerson
FROM:	Ro Windwalker IRB Coordinator
RE:	PROJECT CONTINUATION
IRB Protocol #:	15-03-578
Protocol Title:	*The Prediction of Acute Core and Lower Body Extremity Injuries in Division I Athletes: A Prospective Prediction Model*
Review Type:	☒ EXEMPT ☐ EXPEDITED ☐ FULL IRB
Previous Approval Period:	Start Date: 03/12/2015 Expiration Date: 03/11/2016
New Expiration Date:	03/11/2017

Your request to extend the referenced protocol has been approved by the IRB. If at the end of this period you wish to continue the project, you must submit a request using the form *Continuing Review for IRB Approved Projects*, prior to the expiration date. Failure to obtain approval for a continuation on or prior to this new expiration date will result in termination of the protocol and you will be required to submit a new protocol to the IRB before continuing the project. Data collected past the protocol expiration date may need to be eliminated from the dataset should you wish to publish. Only data collected under a currently approved protocol can be certified by the IRB for any purpose.

This protocol is closed to enrollment. If you wish to make *any* modifications in the approved protocol, including enrolling more participants, you must seek approval *prior to* implementing those changes. All modifications should be requested in writing (email is acceptable) and must provide sufficient detail to assess the impact of the change.

If you have questions or need any assistance from the IRB, please contact me at 109 MLKG Building, 5-2208, or irb@uark.edu.

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