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# An Examination of Time Loss, Injury Rates, and Factors Associated with Injury in NCAA Division I Men's Soccer

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An Examination of Time Loss, Injury Rates, and  
Factors Associated with Injury in NCAA Division I Men's Soccer

Andrea R. Fortunati

B.S. in Athletic Training, University of Vermont, 2014

A Thesis

Submitted in Partial Fulfillment of the

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APPROVAL PAGE

Masters of Science Thesis

An Examination of Time Loss, Injury Rates, and  
Factors Associated with Injury in NCAA Division I Men's Soccer

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## ABSTRACT

An Examination of Time Loss, Injury Rates, and Factors Associated with Injury in NCAA Division I Men's Soccer

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**CONTEXT:** Time loss (TL) at the collegiate level is multifactorial, and includes reasons due to: injury, illness, academic associations, coach initiated modification, and other.

Injury rates (IR) differ by season and exposure setting, and can be examined in a multitude of ways. Injuries vary by mechanism, severity, location, and type, and often result in TL from participation. **OBJECTIVE:** To determine reasons for TL, compare IR between a collegiate men's soccer team during the 2015 season to previously published National Collegiate Athletic Association (NCAA) rates, and evaluate factors associated with injury in 4 soccer athletes. **DESIGN:** Mixed methods observational field study with a case series component. **SETTING:** Outdoor and indoor field and laboratory setting.

**PARTICIPANTS:** Thirty-four male NCAA division I soccer athletes (mean $\pm$ sd; age 20 $\pm$ 2, height 181.6 $\pm$ 6.1cm, body mass 80.2 $\pm$ 7.9kg, body fat 12.8 $\pm$ 2.8%, VO<sub>2</sub>max 52.4 $\pm$ 5.2ml $\cdot$ kg $\cdot$ min<sup>-1</sup>). **METHODS:** Five phases of data collection occurred between 1/19/15-11/22/15 that divided the training season into: offseason, summer, preseason, in-season, and postseason as per the NCAA. Time loss data for all 34 participants were collected during 4 of 5 phases, summer excluded. Injury rate data were collected during these same phases in all 34 participants during formal training, strength and conditioning (S&C), and matches. Measurements of both internal and external load were descriptively analyzed and compared to injury in all 28 field-players. Exposure hours were calculated by researchers that observed practice and recorded individual's exposure time. Player

Load<sup>TM</sup>, training impulse (TRIMP), and time in heart rate (HR) reserve zones (85%-100%) were collected using global positioning systems units and HR monitors. **MAIN OUTCOME MEASURES:** Time loss (injury, illness, academic, coach initiated modification, and other), IR per 1000 athlete exposures (AE) by season, IR per 1000 exposure hours (EH), IR by exposure setting, and 4 case studies with factors that associated with injury were examined. **RESULTS:** Overall IRs were 2.1 injuries per 1000 EH for formal training, 2.3 per 1000 EH during S&C, and 35.6 per 1000 EH for matches, respectively. Seasonal variations were observed with the highest IR during matches in preseason with 60.6 injuries per 1000 EH, and fewest during S&C sessions in-season with 0.0 injuries per 1000 EH. Of all reasons for TL (n=436hrs), 4.2% (n=18hrs) attributed to coach initiated modifications, 4.6% (n=20hrs) attributed to illness, 12.1% (n=53hrs) for other reasons, 18.8% (n=82hrs) due to academic, and 60.3% (n=263hrs) from injury. Time loss was lowest during preseason (n=29hrs), and most during the in-season (n=157hrs). Further research is needed to assess specific factors associated with injuries to create an injury predication model. **CONCLUSIONS:** Time loss due to injury (60.3%) comprised the greatest percentage of overall reasons for TL; therefore, methods to prevent or minimize risk of injury should be implemented. Injuries should be examined using a consistent definition of an injury, and IR should be calculated per 1000 EHs if individual training duration is possible. More research is needed to assess factors associated with IR as seen in cases 1-4.

Key Words: time loss, injury rates, exposure hour, athlete monitoring

## **CHAPTER I: Review of the Literature**

### **1.1 Technology and the “Business of Soccer”**

Soccer is the most popular sport in the world played by 270 million people, or approximately 4% of the population.<sup>1</sup> Given its continued growth and popularity, the sport is played both competitively and recreationally from youth to professional levels by males and females. Being the most played sport in the world brings with it the “business” of sport where ticket sales and championships drive revenue. Unfortunately, in this world athletes are viewed as precious commodities used to drive ticket sales, purchase of memorabilia, and television rights. Often careers hinge on their ability to perform consistently without injury, especially for high profile players whose fans will pay specifically to see them play. That all being said, each organization is looking for the next best way to keep their star players on the field, win their league, and succeed overall as a club or organization. This often comes down to reducing time loss (TL) and injuries while balancing the high demands of training and in-season scheduling. Recent advances in the fields of sports medicine and strength and conditioning (S&C) coupled with advances in sports performance monitoring have led to a massive “datafication” of sport. This datafication of sport through advanced analytics software and wearable technology has helped coaches, athletes, and exercise scientists make better decisions about their players. Decisions that have the potential to prevent injury, optimize training, keep players on the field when it matters, fans in the seats, and keep the “business” flourishing. However, before we dive into the impact of wearable technology, a review of the evolution of the game of soccer is warranted.

Like many sports, soccer has evolved over time and rules have significantly impacted the game. From the introduction of the whistles for referees in 1878 to the introduction of wearable electronic devices in 2015, we can see how the game has evolved (Table 1.1). It is important to understand not only how rules impact the style of play, but also in the risk of injury. Fédération Internationale de Football Association (FIFA), the sport's international governing body, have implemented rules in an effort to decrease injury rates (IR). Such rules include the implementation of shinguards, and red card penalties for an elbow to the head. A study performed in the Netherlands showed a 25% decrease in injury incidence in the four years following the implementation of shinguard use in amateur soccer athletes.<sup>2</sup> Additionally, FIFA reports a decline in concussions and head injuries in Germany since the implementation of a red card penalty from an elbow to the head.<sup>3</sup>

**Table 1.1: Evolution of Soccer Laws, Rules, and Notable Changes.**

1855	First rubber soccer ball was created (sculls, pig's bladder, round objects from animal skins were used prior) <sup>4</sup>
1863	Unification of rules and creation of English Football Association (FA) Offside rule
1886	IFAB was created from four associations of the United Kingdom (England, Scotland, Wales, and Ireland) and met to guard the laws of the game
1869	Goal-kicks introduced
1872	Corner-kicks introduced
1878	Referees used whistles for the first time
1891	Law 14: The Penalty Kick. Creation of having a penalty, originally called "the kick of death." Taken anywhere along a 12-yard line
1902	Penalties were taken at the 18 yard line
1904	FIFA founded
1912	Goalkeepers prevented from handling the ball outside the penalty area
1913	FIFA joined the IFAB
1920	Offside throw-ins were banned
1925	3 player offside rule turned into a 2 player offside rule
1992	Goalkeepers were banned from handling deliberate back-passes
1994	FIFA Medical Assessment and Research Centre (F-MARC) independent research unit established <sup>3</sup>
1998	Tackle from behind now a red-card offence
1990	FIFA mandates shinguards during matches <sup>2</sup>

- 1991 NCAA mandates shinguards<sup>5</sup>
- 2006 Elbow to the head results in a red-card<sup>3</sup>
- 2007 NCAA requires NOCSAE approved shinguards<sup>5</sup>
- 2015 FIFA approved the use of wearable electronic performance and tracking system (EPTS) during competition as long as information is not relayed to coaches during the match<sup>6</sup>

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IFAB: International Football Association Board; FIFA: Fédération Internationale de Football Association; NCAA: National Collegiate Athletic Association; NOCSAE: National Operating Committee on Standards for Athletic Equipment

One of the more recent major rule changes influencing the game of soccer was the approved use of wearable devices during FIFA matches. This change has opened a new window to the science of sports, allowing us to evaluate athlete's physical and medical condition before, during, and after activity. Since the advent of global positioning systems (GPS) in the early 2000's, and more recently small accelerometers equipped with magnetometers and gyroscopes, wearable technology has come a long way in a relatively short timeframe and is being permitted for use even at the highest level of competition. Wearable technology by definition involves devices such as heart rate (HR) monitors, GPS devices, gyroscopes and accelerometers to measure players work loads to monitor factors of stress and fatigue.

Recently in 2012, the National Collegiate Athletic Association (NCAA) added regulations in regards to athlete monitoring: "4.5.6 Players may wear a device for the purpose of monitoring and accumulating data. However, the data obtained may not be used at any time during the game or intervals, unless verified as medically necessary."<sup>7</sup> As previously stated above, on July 7, 2015, FIFA announced the use of wearable tracking systems during major league soccer matches.<sup>6</sup> To date, athlete monitoring has become the norm for many professional<sup>8</sup> sports teams and is becoming increasingly popular at the collegiate<sup>9</sup> level. Wearable technology is used on collegiate athletes at the University of Central Florida, University of Kentucky, University of Oregon and Florida State University to name a few. Athlete monitoring is also used at high school and youth

settings, and is seen at youth soccer schools such as at the Philadelphia Union Academy.<sup>10</sup> Purposes of athlete monitoring are to improve performance and aid in injury prevention associated with the sport related to overuse and fatigue.<sup>11-14</sup>

Wearable sensor technology allows for additional measurements of athlete monitoring, and provides athletic trainers and the coaching staff with valuable physiological data. These data include player movement, biometric markers and workloads, which can be used to alter training, improve fitness, maximize physiological condition, and analyze stressors, all with the goal of improving performance and preventing injuries.<sup>11</sup> Teams such as the New York Knicks have reported in 2013 using GPS measurements to return injured athletes to play based off their preseason, and pre-injury, GPS numbers.<sup>15</sup> Wearable devices themselves are becoming ubiquitous among the entire population with recent reports suggesting that wearable sales are up 1,886% in the past four years.<sup>16</sup> Additionally, Tractica reported that wearable device shipments reached 85 million units in 2015, and are expected to increase to 559.6 million units by 2021.<sup>17</sup> There are a variety of wearable devices currently on the market for the purpose of athlete monitoring. The GPS devices currently being utilized by team sports include those from Catapult Sports, STATSports Viper System, and GPSports to name a few.<sup>11</sup>

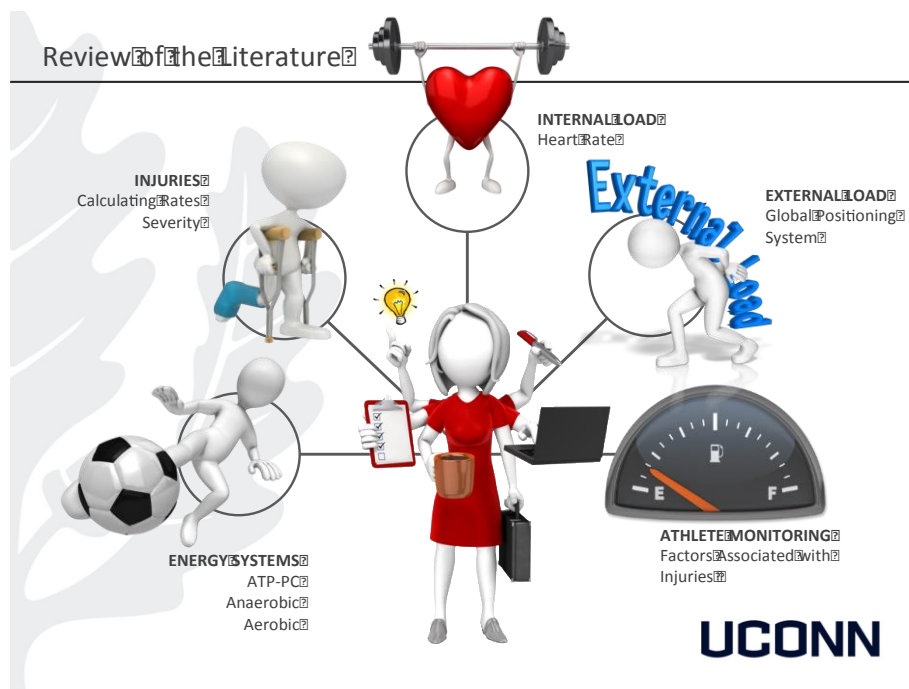
Recently, additional physiological monitoring technology has been integrated to these GPS systems that use Bluetooth technology to transmit data real-time to software, which attempts to depict the internal stress in a useable fashion. One such example of integrated physiological monitoring is the Polar Team Pro, which is a GPS device with built in HR sensors and Bluetooth technology. This technology is still being tested but it



is unique in that it can allow for a more affordable way to measure player load and accelerations, and minimize athletic equipment to one device.

## 1.2 The Physiology of Soccer

There are many positive physiological effects associated with exercise including improved cardiovascular function or efficiency of the heart. Exercise also decreases the risk of cardiovascular disease and certain cancers, while simultaneously improving resting blood pressure and body fat percentage.<sup>18</sup> The extent to which exercise-related physiological adaptations occur vary depending on the acute program variables such as duration, type, intensity, frequency, rest, and timing of exercise performed. Furthermore, adaptations differ depending on which energy systems are routinely utilized to complete the physical activity.



During exercise, metabolic energy is transferred through three main energy systems; the adenosine triphosphate (ATP) and phosphocreatine (PC) system, anaerobic system, and aerobic system. The utilization of each system differs based on duration and intensity, sport specific positions, and fitness levels. Soccer is unique in that all three energy systems are utilized. The immediate phosphagen energy system (ATP-PC) provides energy for exercise that occurs during short durations < 60 seconds at high intensities.<sup>19</sup> This can be seen during high intense, short sprints in a soccer match, penalty kicks, and one maximal repetition during S&C training. Strength and power are additionally necessary for a soccer athlete to increase force in muscular contraction to aid in acceleration, speed, and movements that include change of direction, tackles, passing, jumping for the ball, and duel play.<sup>20</sup>

The anaerobic system utilizes fast glycolysis and is a form of short-term energy seen during maximal efforts lasting 60-180 seconds in duration. This system accumulates lactic acid in the muscle, and is based on fitness level. Lactic acid accumulates when fast twitch, or Type-II, muscle fibers are activated and primarily used during high intense, power exercises. Type II muscle fibers have a rapid force development, high actomyosin myofibrillar ATPase activity, and high anaerobic power.<sup>21</sup> Type I, or slow twitch, muscle fibers are primarily used in the aerobic system. These fibers are fatigue resistant and have a high capacity for aerobic energy supply while Type II fibers are predominantly used for strength and power, and are less resistant to fatigue.<sup>19</sup> The anaerobic system can be seen more in goalies than field players. Fast twitch fibers favor the conversion of pyruvate, which allows the lactate to build up. These energy systems are all utilized in soccer to varying degrees, however, in order to

gain a better understanding of each player's ability both in an anaerobic and aerobic state it has been suggested that fitness status be measured periodically to gain an understanding of each player's anaerobic<sup>22</sup> and aerobic<sup>23</sup> capacity.

### **1.21 Athlete Assessments**

The utilization of laboratory-based physiological testing for performance has become more common at the elite and collegiate levels. Exercise scientists are working alongside coaches, S&C professionals, and the sports medicine team to gain a greater understanding of each player's ability and areas to improve. Two common testing areas in soccer specifically are related to 1) Aerobic fitness and 2) Anaerobic fitness. The next two sections will highlight the common methods of testing in each of the aforementioned areas and how they are connected to soccer performance. Furthermore, it will discuss the role of S&C.

*Anaerobic Fitness Assessment.* It is imperative for a soccer player to be anaerobically fit due to the fast paced nature of the sport that requires high intensity running, and fast, explosive movements. Lactate is a by-product of glucose metabolism, and accumulates during high-intensity activity such as sprinting for the ball. Since a soccer match lasts for 90 minutes, low-intense activity must be provided in order for lactate removal or buffering/shuttling out of the muscle to occur,<sup>20</sup> therefore testing this anaerobic ability can be very important. Assessing anaerobic fitness can be measured in a variety of ways. One common laboratory method is known as the lactate threshold test. Resting lactate occurs at ~1 millimole per Liter (mmol/L), and exercise intensity influences the onset of blood lactate accumulation (OBLA); which is measured when blood lactate reaches a concentration of 4 mmol/L and is assessed during a graded

laboratory exercise test. This test consists of a graded exercise protocol with increasing intensity while lactic acid is measured every two minutes, until 4 mmol/L is exceeded. Although there are many conflicting arguments surrounding the precise level or method used to determine this, the accumulation of blood lactate is found to occur around 50% of the maximum capacity for aerobic metabolism for untrained athletes, and approximately 75% in trained athletes.<sup>19</sup> These measurements are important and can predict an athletes' endurance performance; the higher an athletes' blood lactate threshold, the more anaerobically fit they are and the better they are at buffering the lactic acid produced from their system to prepare for the next required bout.<sup>24</sup>

*Aerobic Fitness Assessment.* Although the anaerobic system is utilized in soccer, the aerobic energy system is the primary source of energy. The aerobic system utilizes the oxidative system and the long-term source of energy that is transferred when intense exercise exceeds several minutes, and can be maintained for extended periods of time, dependent on the individual's aerobic state. Aerobic fitness can be measured through a multitude of measures both in laboratory and field based settings by testing an individual's maximal oxygen consumption ( $\text{VO}_2\text{max}$ ).  $\text{VO}_2\text{max}$  represents an athlete's physiological capability and determines the intensity of exercise they can withstand for a specific duration, with a higher value representing a more aerobically fit athlete. The two methods most commonly used are the  $\text{VO}_2\text{max}$  and Yo-Yo Intermittent Recovery (Yo-Yo IR) testing protocol.<sup>25</sup> This is done accurately in a laboratory setting where the athlete is connected to a computer based metabolic cart. The  $\text{VO}_2\text{max}$  laboratory test is done in a controlled environment and calculates the cardiorespiratory fitness of an individual by measuring the amount of  $\text{CO}_2$  the individual expires during the test. This

test also factors in an individual's height, weight, age and sex. Given the time consuming and costly nature of this test it is often impractical when measuring an entire team. Soccer coaches have estimated  $\text{VO}_2\text{max}$  in a field-setting for entire teams through the Yo-Yo IR, or Beep test. The Yo-Yo IR level 1 (Yo-Yo IR1) test is a common method for soccer coaches to measure their teams fitness level.<sup>26</sup> Yo-Yo IR1 consists of the athlete running a 2x20m, with a 10-second active recovery, at increasing speeds. The completion of the test is 3600m, and ends when the athlete is no longer able to maintain speed and reach the required distance, in the appropriate amount of time allotted. Depending on the aerobic capacity, the test takes approximately 10-20 minutes to perform. Though this field test is not an exact measurement, it is an inexpensive and relatively fast way to estimate aerobic fitness for a team by measuring the distances completed. Martinez-Lagunas and Hartmann<sup>25</sup> found that the Yo-Yo IR1 underestimated female soccer players  $\text{VO}_2\text{max}$  by 9.4% when comparing to laboratory testing. Deprez et al.<sup>27</sup> concluded the Yo-Yo IR1 was reliable when comparing the test to itself in youth soccer players. Therefore, when using the Yo-Yo IR1, a coach should compare the test to prior tests, but not to a laboratory test.

Since physiological adaptations occur from targeted training programs, performance measures would reflect that. Additionally, depending on the training program, different adaptations are made. Physiological assessments of athletes vary based on the amount of training performed and level of competition (Table 1.2).

**Table 1.2: Anthropometrics Comparison of Untrained Males, Collegiate Soccer Male Athletes, and Elite Soccer Male Athletes.**

	<b>Untrained Males</b>	<b>NCAA Division I Men's Soccer (n=34)</b>	<b>Elite Male Soccer Athletes</b>
Age (y)	-	20.7 ± 1.51	25 ± 3.50 <sup>28</sup>
Height (cm)	179 ± 7 <sup>29</sup>	181.6 ± 6.1	172.8 ± 7.3 <sup>28</sup>
Body Mass (kg)	77 ± 9 <sup>30</sup>	80.2 ± 7.9	79.4 ± 1.6 <sup>28</sup>
Body Fat (%)	19.7 ± 1.5 <sup>31</sup>	12.8 ± 2.8	10.7 ± 0.6 <sup>5</sup>
VO <sub>2</sub> max (ml·kg·min <sup>-1</sup> )	44.2 ± 7.6 <sup>32</sup>	52.4 ± 5.2	61.6 ± 0.6 <sup>33</sup>
Yo-Yo IR1 Distance (m)	1000 - 1520 <sup>34</sup>	3002 ± 501	2475 ± 421 <sup>35</sup>
Yo-Yo IR1 Est. VO <sub>2</sub> max <sup>26</sup>	44.8 - 49.17 <sup>5</sup>	61.6 ± 4.21	57.19 ± 3.54 <sup>35</sup>

NCAA: National Collegiate Athletes Association; IR1: Intermittent Recovery test 1

Testing both anaerobic and aerobic fitness can be a valuable tool, however it is important to note that in soccer, each position calls upon different energy systems in varying capacities. Due to the nature of the sport, a goalie will not need their aerobic energy system trained similarly to someone who plays on the field, whereas a field player may not utilize their ATP-PC system to the same degree as the goalie. Even though a match lasts 90 minutes, anaerobic components are largely used along with maximal power and explosive movements in all positions. Distinctive energy systems and muscle fiber types are used differently in each unique player position. Mallo et al.<sup>36</sup> reported that wide-midfielders cover the longest distances in very-high intensity running, wide and central midfielders covered the greatest distance, whereas central defenders have the most accelerations compared to forwards, wide midfielders and fullbacks. It is imperative to the success of an athlete and to the team to have individual training programs based upon player position to not only technically train the athletes, but also to train the necessary metabolic systems. When training a soccer athlete, aerobic capacity, anaerobic power and anaerobic capacity must all be taken into consideration.

*Strength & Conditioning.* For an athlete to be successful on the field, additional strength requirements are found to be beneficial and aid in injury prevention.<sup>37</sup>

Performance in soccer is multi-factorial and includes not only physical, but also

technical and tactical skills. It was suggested in a review by Silva et al.<sup>38</sup> that strength with high-intensity training may be the best method of training a soccer athlete within a periodized process. Strength and conditioning training is incorporated into the regular training program at the collegiate and professional level and are designed to increase muscular strength, endurance and flexibility. Strength training may vary throughout the season, with more intense resistance training in the offseason. Many S&C professionals utilize periodization (linear or non-linear) to accomplish their strength goals.

Periodization of strength training is also divided into three distinct phases: preseason (preparation period), in-season (competition period), and offseason (transition period). These periods do not occur in sync with the seasons in collegiate soccer in that the preparation period phase of strength training is not initiated during preseason of soccer, but during the offseason of soccer. One of the major concepts or goals of strength training initially are to gain specific neural adaptations and enhance neural plasticity.<sup>21</sup> These adaptations occur during different intensity zones based off the percent of the individual's maximum repetition and include intramuscular coordination such as synchronization and recruitment, intermuscular coordination, disinhibition of inhibitory mechanisms and specific hypertrophy.<sup>39</sup> When training an athlete for the purpose of strength and power, personalized weight programs are provided to the athlete based off their capabilities, as measured by their 1 rep max (RM). However, this exact technique does not transfer to the field when training a soccer athletes aerobic energy system. Measuring strength and power for soccer athletes can be performed in a multitude of ways that include: 1 RM, vertical jump, agility testing such as the 5-10-5, and the 40-yard dash. The vertical jump test measures anaerobic power and muscular strength,

which is highly correlated with athletic performance.<sup>22</sup> These tests are useful when measuring variations in physiological fitness amongst individuals over the course of a season.

### **1.22 The Sport of Soccer**

Although not physiological in nature, there are a few areas where the sport of soccer differs from level to level and country to country. These include the portions of year considered to be preseason, in-season, and postseason, and field dimensions. A competitive soccer season at the collegiate level in the United States can be divided into: preseason, in-season, and postseason. Preseason can be defined as the period of time before the regular season begins, and tends to occur in August. It is the shortest season, but often thought of as the most intense training period. In-season is played in the fall where an average of 18 matches are played at the NCAA Division I level.<sup>5</sup> Postseason is the season that directly follows in-season, and lasts until the final competition match. The offseason tends to last the duration of the spring semester, which, depending on the program, includes practice sessions, scrimmages, and intense strength training. Additionally, the collegiate level encourages training prior to preseason and after postseason with the primary goal during this time to improve strength, power, and overall fitness at high intensities in preparation for preseason.

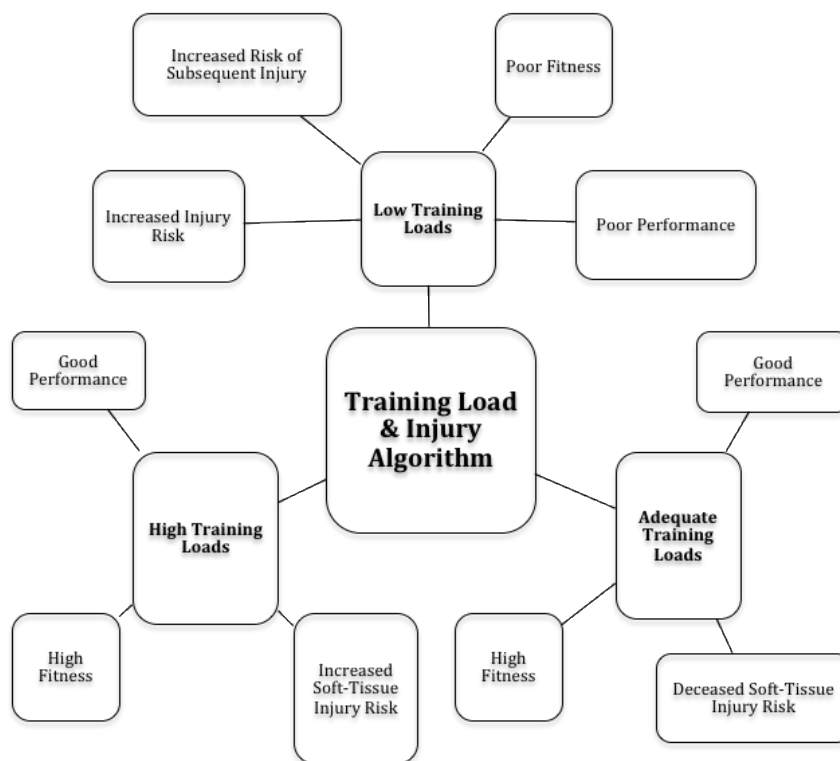
The second area where collegiate sports in the United States differ from other levels and countries are related to the dimensions of a soccer field. The NCAA rule states that a soccer field must be rectangular with a width between 70-75 yards, and length between 115-120 yards with the optimal size 75 by 120 yards. Some may consider field size to be insignificant but research has demonstrated that field restrictions



increase the number of turns, change in pace, change in direction and forceful contractions endured.<sup>20</sup> This in turn can impact the style of play as well as training goals. A soccer match is played during two 45-minute periods with a 15-minute half time. Two ten-minute sudden victory overtimes occur if the score is tied after a five-minute break following the full regular match time, with two-minutes between overtime periods. All eleven players can be substituted at once, but there are strict re-entry rules. Substitutions consist of no re-entry during the first half, one re-entry during the second half, and no re-entries during overtime periods. These rulings, in theory, allow for players to exit the match and have sufficient time to refuel their energy levels before returning to play. However, often due to a player's importance to the team's success, this often does not take place. Therefore, based on the ruling, it is common for a player to participate in an entire match. For an athlete to maintain maximal performance for the duration of the match, proper training programs should be initiated. This is where wearable technology becomes vital and advantageous to the athletes and their team.

Wearable devices capable of monitoring the physiology or internal stress while simultaneously assessing the external stress (i.e. time spent at high intensity) of players during training and competition, provide those on the sideline with insightful information to make key decisions and potentially change the strategy of attack or manage changes in personnel.<sup>12,40</sup> Just one of the many variables that are commonly monitored to inform these decisions are distance covered. Studies show that the average distance covered in a match for a field player is approximately 11 km.<sup>36,41,42</sup> Using these reported norms they can assess and compare whether or not an athlete should remain in the match or be substituted. Furthermore, if a player is known to routinely cover more

distance than other players, the training program can be modified to adequately prepare this athlete for the increased load. In theory, these devices can help the athlete accomplish this task while avoiding serious physical consequences through continuous monitoring in not only matches, but also all training sessions where an athlete is at risk for injury. Gabbett<sup>43</sup> recently published the “Training-Injury Paradox” as demonstrated in the training load and injury algorithm (Figure 1.1). This study demonstrates high chronic workloads may reduce injury, excessive increases in workloads, and underexposure, may increase the risk of injury. These findings suggest benefits to calculating training load placed on individual athletes in correlation to possible injury prevention.



**Figure 1.1. Training Load and Injury Algorithm.** (Modified from Gabbett<sup>43</sup>)

### **1.3 Injuries in Soccer**

Injuries are an inherent part of any physical activity, especially when participating in competitive sport. Recently, there has been a push within sports medicine and exercise science at both the collegiate and professional levels to determine the common factors that are associated with injury in an effort to keep players healthy and avoid long-term or career-ending injuries. Many investigators are currently examining ways to develop injury prediction models, with special focus on noncontact lower extremity musculoskeletal injuries.<sup>13,44-48</sup> Lehr et al.<sup>45</sup> aimed to create an injury risk algorithm through demographic information, injury history, and movement screening as a relatively cheap way to predict lower extremity musculoskeletal injuries at the collegiate level.<sup>45</sup> In contrast, other studies performed at the professional level utilize rather expensive measuring tools such as GPS and HR devices to determine risk of soft tissue injuries.<sup>13,44</sup> Although both methods appear to have merit, it appears that there is a stronger move towards more expensive and integrated technologies because of the advanced analytics that they provide. Either way, both methods require the appropriate personnel to interpret the data in a meaningful fashion if we are ever going to prevent injury. Simply stated in Goldilocks Principle,<sup>49</sup> is the “just right” reference which can be translated to sport<sup>50</sup> when utilizing data from wearable devices such as GPS units. There are currently no studies that show what performance is expected of a soccer athlete to train at in order to remain “just right” when aiming to prevent injuries. There is no reported defined parameter load with which athletes need to remain in respective to training programs and injury prevention.

The etiology of soccer injuries is multifactorial and may include both intrinsic and extrinsic factors. Intrinsic factors can include individual factors such as fatigue, stress, and load, whereas extrinsic factors are those out of the players control and involve environmental conditions, playing surface, training intensity, match importance, and so forth.<sup>51</sup> There are many injury risk factors, screening tests, and preventative exercises that were concluded from a systematic review on 44 soccer teams as depicted in Table 1.3, adapted from McCall et al.<sup>52</sup> Previous injury had reportedly the highest level of evidence; muscle imbalance was inconclusive, all screening tests had a Graded D recommendation among with preventative exercise with the exception of hamstring eccentric had a C.

**Table 1.3: Top 3 Risk factors, Screening tests, and Preventative Exercises.**

<b>Risk Factor</b>	<b>Screening Test</b>	<b>Preventative Exercise</b>
Previous injury	Functional movement screen	Hamstring eccentric
Fatigue	Questionnaire: Psychological evaluation	Other eccentric
Muscle Imbalance	Isokinetic muscle testing	Balance and proprioception: Knee and Ankle

Modified from McCall et al.<sup>52</sup>

*Injury Rates In Soccer.* Given the large number of competitive players on a field congregating around a small object at one time and considering the fact that protective equipment is only worn on the lower leg, soccer has been shown to have a high percentage of contact injuries. Agel et al.<sup>5</sup> found that over 15 years within NCAA men's soccer, the most common mechanism of injury during match was player contact, and no contact for practices. The mechanism of injuries are classified to occur when an athlete is: running, tackling or being tackled, shooting, twisting/turning, jumping/landing.<sup>53</sup> Examining IR data, rates were highest during a match with 18.75 injuries per 1000 athlete-exposures (AE), and 67.3% of these injuries occurred in the lower extremity

(LE), 12.8% to the head/neck, 6.8% to the upper extremity (UE), and 2.6% in other/system.<sup>5</sup> Head/neck injuries include concussion, and interestingly 60.0% of NCAA male soccer athletes experience concussion injuries during competition, with 70.9% of these concussions due to player contact and 21.8% the result of contact with the ball.<sup>54</sup> The most common injuries that occur are LE musculoskeletal, with over 90% occurring to the hamstring, calf, hip/groin and quadriceps muscle groups.<sup>55</sup> Musculoskeletal injuries are commonly seen in men's soccer, accounting for approximately one third of all TL injuries at the professional level (32-37%).<sup>56-58</sup>

Injuries have been categorized in a variety of ways based off the researcher's definition of an injury, which furthermore influence IR. Injury rates are calculated in dissimilar approaches and have been calculated per 1000 exposure hours (EH),<sup>55,59-62</sup> per 1000 AE,<sup>5,64</sup> and further divided by season,<sup>5</sup> type of exposure,<sup>64</sup> and athlete playing position.<sup>66-68</sup> The varying approaches to IR calculation make it difficult to compare between studies and some methods can tend to inflate the rates by virtue of the manner in which they are calculated. In order to compare IR across varying levels of competition, IRs need to be calculated and reported consistently, Figure 1.2 illustrates the varying methods.

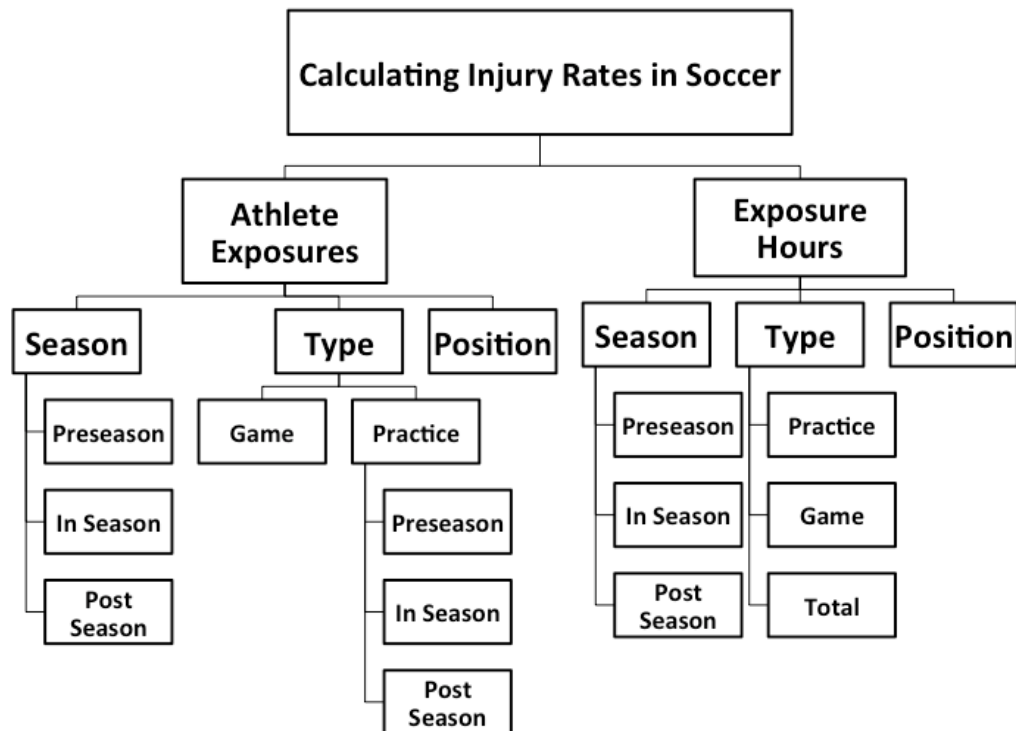


Figure 1.2. Methods of Calculating Injury Rates in Soccer.

An injury is defined if an athlete requires medical attention during a training or competition, and is restricted the following day due to the injury (Table 2.12).<sup>69</sup> Most injuries are the result of non-contact during explosive running and the reported number of high-force eccentric contractions.<sup>70</sup> Musculoskeletal injuries in soccer have also been classified by their mechanism of injury being acute versus chronic. Based on the common definition, an acute injury occurs from one trauma during one identifiable event, whereas an overuse injury does not occur during one event and is seen with a gradual-onset.<sup>71</sup> Muscle injuries account for 18-23% of TL injuries at the amateur level, and 20-37% at the professional level.<sup>55</sup> Acute musculoskeletal injuries and severe injuries have remained the same as seen in a study performed by Ekstrand et al.<sup>72</sup> on an 11-year injury study follow-up of the UEFA champions league. The same study

concluded ligamentous IRs declined by 31% in this time.<sup>72</sup> Ligamentous injuries are seen in the lateral ankle (6.9%), third most common to hamstring injuries (12.8%) and adductor injuries (9.2%).<sup>72</sup> Injuries that fall under the severe category tend to involve bone injuries and occur from direct contact. One study examining fractures in Belgian soccer players found that even with the required equipment of skinguards, lower extremity fractures accounted for 36% of fractures.<sup>51</sup> Of these, 75% occurred during competitive matches and were highest at the foot (33%), ankle, tibia (22%), and fibula (9%). Fractures of the fibula were highest during matches (81%), and fractures of the foot were highest during practice (33%). Overuse muscle injuries account for 33.9% of overall overuse injuries,<sup>66</sup> where preseason overuse injuries tend to be the highest. These data are supported by Agel et al.<sup>69</sup> who determined that collegiate male soccer athletes had a preseason training IR of 8.1 per 1000 AE compared to a postseason practice IR of 1.9 per 1,000 AEs. Table 1.4 demonstrates practice and (game) IRs as calculated per 1000 AEs per season.

**Table 1.4: Practice and (Game) Injury Rates per 1000 AE per season in NCAA Athletes.**

Study	Subjects	Preseason	In Season	Post Season	Off Season	Total
Hootman et al, 2007 <sup>63</sup>	Division I	7.28 (7.01)	2.4 (16.24)	1.59 (9.47)	-	4.27 (15.47)
Agel et al, 2007 <sup>5</sup>	Division I Men's Soccer	8.1 (21.32)	2.8 (22.23)	1.9 (16.28)	-	4.6 (21.92)
Kerr et al, 2015 <sup>73</sup>	Men's Soccer	-	-	-	-	5.26 (17.89)

AE: Athlete Exposure; NCAA: National Collegiate Athletic Association

Going a step further, injuries in a match were highest at the start and end of the season.<sup>74</sup> Another investigation concluded IRs were highest during the first 15 minutes of each half in a match, suggesting improper amount of warm-up time.<sup>75</sup> There are a variety of contributing factors associated with the risk of injury, these include, but are not limited to the following: age, sex, medical history, level of competition, athlete exposure,

environmental setting, timing of injury, and location.<sup>76</sup> Various studies have also examined IRs by position (Table 1.5), with no uniform method of reporting the data.

**Table 1.5: Summary of Studies Comparing Overview of Injury Incidence by Position.**

Study	Statistics	Keeper	Fullback (Defender)	Central- defender (Defender)	Central midfielder (Midfield)	Wide- midfielder (Midfield)	Forward
Carling et al. 2010 <sup>66</sup>	95% CI, means±SD	23.8 (6.2-41.4)	41.0 (24.6-57.4)	35.7 (20.4-51.0)	36.3 (23.3-49.3)	32.2 (17.7-46.7)	77.2 (49.1-105.3)
Morgan & Oberland, 2001 <sup>67</sup>	1000 EHs	5.59	5.63		6.56		5.87
Mallo & Dellal, 2012 <sup>68</sup>	Team Percent Distribution	2%	14%	22%	14%	17%	32%

EH: Exposure Hour

Playing position<sup>66-68</sup> and age<sup>77</sup> have been determined to be pre-disposing factors to injury. Mallo & Dellal<sup>68</sup> reported forwards have the greatest risk with 32% of a team's injury incidence. Risk of soccer injury increases with age, peaks at 20-24 years, and subsequently declines. This may attribute to the fact that the volume of athletes generally decrease with age. Kristenson et al.<sup>77</sup> examined professional soccer players over the course of 9 athletic seasons and observed IR increase with age. One exception to this increase was that stress-related bone injuries were highest in those with the fewest athletic seasons, or incoming athletes. Furthermore, elite male soccer players sustain approximately one performance-limiting injury each year,<sup>78</sup> and an average of two injuries per season.<sup>72</sup> Injuries that prevented an athlete from performing in sport at the professional level account for 11-12% of all TL.<sup>79,72</sup> Additionally, male athletes experience more contact injuries during match play than females suggesting males play at a higher intensity.<sup>78,79</sup> Injury rates at the professional level are calculated per 1000 EH, which differs from the collegiate level where the NCAA calculates IR per 1000 AE. Table 1.6 shows a breakdown of IR at the professional level based off of 1000 EH for: practice, match and overall rates.



**Table 1.6: Soccer Injury Rates/Incidence per 1,000 Exposure Hours.**

Study	Participants (N size)	Year	Practice	Match	Total
Morgan & Oberlander, 2001 <sup>60</sup>	MLS (10 teams: 237)	1996	2.9	35.3	6.2
Rahnama et al., 2002 <sup>75</sup>	English Premier League (220)	1999-2000	-	53.0	-
Häggglund et al., 2003 <sup>61</sup>	Elite Swedish (12 teams: 180)	1982	4.6	20.6	8.3
Häggglund et al., 2003 <sup>61</sup>	Elite Swedish (14 teams: 312)	2001	5.2	25.9	7.8
Häggglund et al., 2005 <sup>62</sup>	Elite Danish (8 teams: 188)	2001	11.8	28.2	14.4
Häggglund et al., 2005 <sup>62</sup>	Elite Swedish (14 teams: 310)	2001	6.0	26.2	8.2
Ekstrand et al., 2011 <sup>58</sup>	European Professional (23 teams) UEFA	2001-2008	4.1	27.5	8.0
Mallo & Dellal, 2012 <sup>68</sup>	Professional Spanish (35)	2007-2009	3.9	31.1	6.6
Van Beijsterveldt, 2015 <sup>59</sup>	Professional Dutch (217)	2009-2010	2.1	31.8	6.2

MLS: Major League Soccer; UEFA: Union of European Football Association

One major limitation of the table depicted above is that there is non-uniformity in the definition of injury, so it is unknown if IRs were higher/lower based on the definition alone. Studies by Häggglund<sup>61,62</sup> and Ekstrand et al.<sup>58</sup> followed Ekstrands injury definition from 1982, which defined an injury that occurred in a scheduled training or match, and caused the athlete to miss the next session or match. This is slightly different than the definition of Fuller et al.,<sup>80</sup> who published a consensus statement in 2006 on injury definitions and data collection procedures for soccer, classifying an injury as one occurring in a training or match, and a TL injury as: “an injury that results in a player being unable to take a full part in future football training or match play.” The NCAA defined an injury as one that required restriction of the athletes’ participation for 1 or more calendar days beyond the day of injury.<sup>69</sup> Therefore, slight variations are seen with injury definitions. Ekstrands definition stated a training or match must be missed, Fullers

TL injury definition required restriction, without a missed day, and the NCAA required restriction the following calendar day.

Measurement calculation of exposure, there has not been a clear consensus as to what an exposure is classified as. Fuller et al.<sup>80</sup> defined a training exposure as: “team based and individual physical activities under the control or guidance of the team’s coaching or fitness staff that are aimed at maintaining or improving players’ football skills or physical condition.” The NCAA defined an exposure as one that has potential of athletic injury while training participating in practice or competition, but does not include EH hours.<sup>69</sup> This is another area where research is lacking and makes comparisons difficult.

*Sex Differences.* There are variations in injury amongst male and females, and males have demonstrated an increased risk for specific injuries.<sup>81,82</sup> Orchard<sup>81</sup> reported collegiate soccer males were 2 times as likely to have a groin injury compared to their female counterparts. Zuckerman et al.<sup>54</sup> reported the concussion rate for females were 1.83 higher relative risk than males. Mufty et al.<sup>83</sup> reported that males sustain more musculotendinous, joint dislocation, contusions and fractures than females. Additionally, males showed a higher IR, whereas females sustained more serious injuries overall. However, Ristolainen et al.<sup>82</sup> analyzed sex differences for a 12-month period, and found few significant differences in injury incidence in males and females when adjusting for exposure time. Hägglund et al.<sup>79</sup> reported the five most common injury diagnoses for males were injuries to the: hamstring, adductor, ankle inversion sprain, quadriceps contusion and quadriceps strain. Females had injuries to the: hamstring, ankle inversion sprain, groin pain, low back pain, and quadriceps strain in descending order.

Despite the contrasting findings on males and females, past medical history of an injury is considered a risk factor for both sexes. McCall et al.<sup>52</sup> found that previous injury was the top for three risk factors associated with injury. The other two risk factors reported were fatigue and muscle imbalance. Similar research by Bjørneboe et al.<sup>74</sup> and Hallén et al.<sup>56</sup> support the previous notion that previous injury is a major factor for injury. Respectively, both Bjørneboe and Hallén observed that 20% and 15% of all injuries were re-injuries. Furthermore, when examining the location of the injury, muscle injuries accounted for 58% of the total injuries and were most commonly seen in the thigh, hip/groin.<sup>74</sup> This again was confirmed by Hallén et al.<sup>56</sup> who determined that re-injuries were highest among adductor, calf, and specifically the bicep femoris of the hamstring group.

The setting associated with an AE has a varying IR. An athlete is more likely to get injured during a match than a training session at any level.<sup>74</sup> A study conducted by the NCAA concluded that a collegiate male soccer athlete was 4x more likely to get injured during a match compared to a training session,<sup>5</sup> and within matches, there are varying elements that influence IRs. It was found in a study by Bengtsson et al.<sup>84</sup> that there is a higher risk of injury associated with: home matches, matches that result in a tie or loss, and championship matches. Injuries also influenced match results in that if two or more injuries occurred, there was a higher likelihood that the team will lose or draw the match. Additionally, multiple studies evaluated match congestion as an increase in IRs.<sup>66,85,86</sup> Carling et al.<sup>66</sup> found injury incidence did not alter with match congestion. In contrast, another study found during match congestion of  $\leq 4$  days between matches,

hamstring and quadriceps strains were higher than when matches were played with  $\geq 6$  days recovery.<sup>85</sup>

In addition to location of play, environmental factors have been shown to have an effect on the type of injury. Both warm and cold environmental conditions have been associated with injuries in sport, specifically in those of environmental heat illness<sup>87</sup> and environmental cold illness.<sup>88</sup> Temperature variations not only effect injuries, but alter activity patterns. Nassis et al.<sup>89</sup> concluded that the number of successful passes in a match improved when played under hot ambient conditions, and the number of sprints declined demonstrating activity modifications with varying environmental changes. In previous years, others have suggested that playing surface (i.e. grass vs. artificial turf) or surface area may be associated with injury in sport. Two prominent studies examining this association reported no difference between incidence of injury and surface area.<sup>65,90</sup> In a recent study by Kristenson et al.<sup>91</sup> no associations between overuse injuries and surface area a match was played on were observed that resulted in TL. In the same study, however the largest variations were seen with 28.3 injuries per 1000 EH when a team played on an away grass surface, and 15.2 injuries per 1000 EH when they play away on natural grass.

*Injury Prevention.* Due to the high number of athletes, the widely televised nature, and popularity of the sport of soccer, it is imperative that each coaching staff incorporates appropriate training for their athletes. Excessive AEs can lead to overuse injuries and overtraining, whereas minimal training can result in a low fitness and can potentially be detrimental to match play outcomes, especially if the athletes are not at the same fitness level as their opponents. Training varies at each level of competition,

skill level, and requirements of the athletes. Regardless of age, sex, playing level and setting, injuries have been an inevitable part of sport participation. In light of this, injury prevention programs have been widely used and initiated for soccer at all playing levels in an attempt to minimize specific injuries that can conceivably be avoided with proper training programs. The FIFA 11+ program is a commonly used injury prevention program among soccer athletes. It incorporates dynamic and core stabilization, plyometric drills, eccentric and proprioceptive training, and can be completed in 10-15 minutes.<sup>48</sup> A recent study performed on NCAA Division I and II collegiate athletes examined the efficacy of the FIFA 11+ program. They found when properly implemented, a reduction of 28.6% of TL due to injuries, and reduced IR by 46.1% in the intervention group compared to the control.<sup>76</sup> F-MARC 11+ is another validated injury prevention program that has proven success in youth female soccer players and in study in 2013 showed a 72% reduction in relative risk in lower extremity injuries in one NCAA Division III male soccer team.<sup>48</sup>

### **Monitoring Soccer Stress**

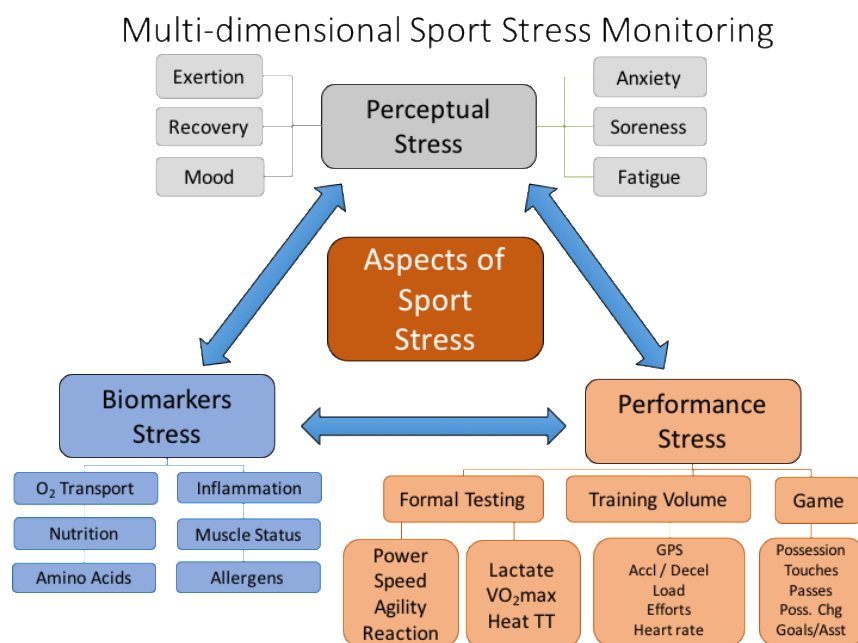
There are not only physical stressors associated with soccer, but many psychological and psychosocial stressors involved with an individuals health and well being, especially at the collegiate level. Collegiate student-athletes are exposed to various forms of stress that can include: academic stress, life stress, social stress, and relationship strains just to name a few. The mental health of an athlete can have a negative and positive impact on their success not only off the field, but can have an effect on their performance on the field. A review by Putukian<sup>92</sup> stated that a decrease in stress could lower injury and illness rates. Stress alone can predispose an athlete to

injury through attention change, distraction, increased self-consciousness, muscle tension and coordination, which can attribute to alterations in performance.<sup>92</sup> Athletes under stress and athletes with depression have an increased risk of injury with an emotional health impact on performance. An investigation by Yang et al.<sup>93</sup> concluded that 23% of student-athletes reported with depressive symptoms, while only 4% reported history of clinically diagnosed depression. This is similar to depressive symptoms found for collegiate students. Additionally, student-athletes reporting with symptoms of depression had a higher State-Anxiety and Trait-Anxiety. Depression symptoms were highest among freshman students, females, and individuals with self-reported pain.<sup>93</sup>

In a study by Sibold et al.,<sup>94</sup> psychosocial health entails four main components: worry, concentration, disruption and negative life stress. These were found to have strong correlations predicting the amount of time to onset of an injury. The stress and injury response in Williams and Anderson<sup>95</sup> model incorporated personality, history of stressors, and coping resources. Acute stressors vary depending on the performance expectations whether for the purpose of power and strength in resistance training, technical and tactical skills in a training session, to the combination of all trainings during a match. There are many factors to be considered for each individual to measure the success of the team as a whole.

Athlete monitoring is seen at higher levels of competition, with more luxurious devices being utilized in the collegiate and professional settings. Limitations to this form of athlete monitoring is the high cost associated with the devices and need for additional personnel to import, manage and interpret the data. An additional method to such devices that is beneficial to the athletic trainer, S&C coach and team coaches can be done at a

very cost efficient method through questionnaires to measure the athletes' perceptual measures. This can be done as cost efficiently with pen and paper, to e-mailing surveys to athletes to complete each day. It is imperative to the health and performance of the athlete that certain measures are tracked in order monitor the athletes appropriately. Figure 1.3 demonstrates the various aspects of sport stress that can be categorized into three main stressors: biomarker stress, perceptual stress, and performance stress. Within these are a plethora of methods of measuring each stressor, with many listed in the figure.



**Figure 1.3. Multi-dimensional Sport Stress Model.** (Huggins, RA, used with permission)

There are many physiological effects and cognitive responses to exercise. Sleep facilitates physiological and psychological functions, which can be critical to performance. Sleep quantity and quality are imperative to optimal performance and recovery in an athlete, with special emphasis on muscle glycogen resynthesis, muscle

damage repair, and cognitive function.<sup>96</sup> Improper recovery can pre-dispose an athlete to an increased risk of injury and poor performance. Fullagar et al.<sup>97</sup> recently published in an article that appeared in 2014 that “a reduction in sleep quality could result in autonomic nervous system imbalance” and “increases in pro-inflammatory cytokines following sleep loss could promote immune system dysfunction.” Factors that could influence sleep acute and chronically entail: mood, away matches and schedules, travel, match result, napping, caffeine, alcohol consumption, polychromatic light in stadiums, early morning training, and individual chronotype.<sup>96</sup> Sleep quantity and quality can be measured cost efficiently for individuals through questionnaires and through wearable devices.

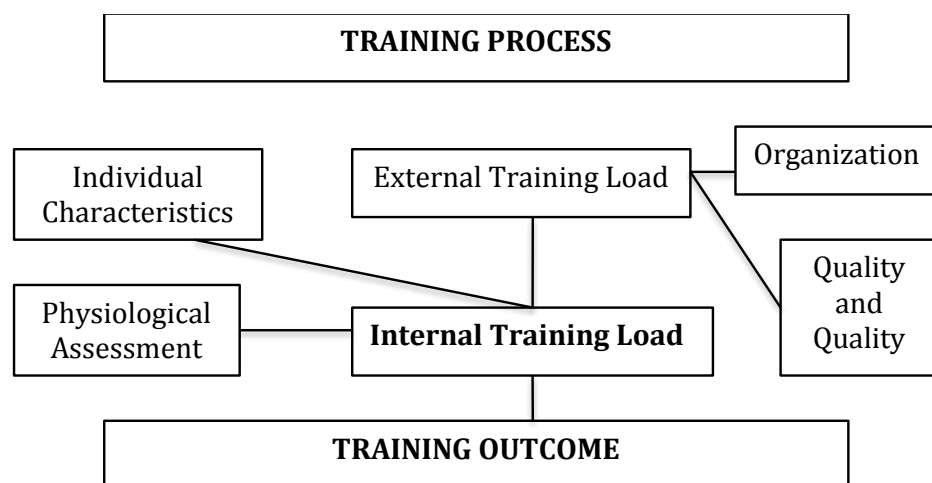
### **1.3 Quantifying Internal Load**

Athlete monitoring has become increasingly popular in measuring an athletes training load in sport. These measures are seen with internal and external training load measurements. Internal training load consists of a wide range of measurements ranging from athletes perception of training to highly sensitive blood biomarkers. Borg’s rate of perceived exertion (RPE)<sup>98,99</sup> scale is an example of a subjective measure of perception of effort following an exercise session. The scale ranges from 6-20, and when multiplied by 10, the scale directly matches HR with an average resting heart rate (RHR) at 60bpm and maximal at 200bpm.<sup>100</sup> Studies have shown strong correlations between RPE with HR and blood lactate<sup>101,102</sup> and was found to be an appropriate measurement in monitoring exercise intensity. Another method for monitoring internal training load that is often more invasive and costly is via blood biomarkers.



*Blood Biomarkers.* Biomarkers can aid in determining the amount of internal stress an athlete is placing on their physiological system. Heisterberg et al.<sup>103</sup> collected blood biomarkers in elite soccer players over five consecutive months. Results of the study found significant differences in leukocytes and monocytes when comparing to various time points in the season, and the highest change in creatine kinase and basophilocytes.<sup>103</sup> Blood biomarker results can have numerous benefits to a coach. If an athlete's immune system is impaired, as demonstrated by the change of basophilocytes, their ability to perform and maintain their training load will create an increased stressor on the individual. Knowing when creatine kinase levels, a muscle damage marker, are high at various time points of the season can aid a coach when creating and tailoring individual training programs. Decreased levels of leukocytes have been associated with overtraining and overreaching, and would provide important information regarding immune function, which may be an important measurement to analyze.<sup>103</sup> Measuring immune parameters in general can detect changes in health, which is especially critical to professional athletes whose career depends on their health. Some have suggested that biomarkers when coupled with performance testing such as assessments of peak power output can indicate muscle fatigue. One example of this was conducted in an investigation by Russell et al.<sup>8</sup> where creatine kinase (CK) levels were measured in conjunction with peak power output through countermovement jump (CMJ), 24 hours pre match, and 24 and 48 hours post match, finding a relationship between the change 24 hours post match, but not 48 hours. This study suggested the use of CMJ as an indicator of muscle fatigue following a match in relation to CK levels, and can be used to tailor training.

*Training Load.* Another measurement tool recently used in sports performance when there is a lack of technology available is the use of training load, which refers to the physical stress performed by an athlete based on the amount of training. Training load can be collected and calculated in various ways. One way training load can be calculated is by collecting an athletes overall session RPE times training duration.<sup>43,104–106</sup> One study found that a training load of 3,000-5,000 arbitrary units (AU) in one week, found a 50-80% increased risk of injury during preseason.<sup>43</sup> This method aims to combine both internal load from RPE, which is strongly correlated with heart rate, and external load in the form of duration. Figure 1.4 demonstrates the training process, and how internal training load is an important measure to collect when examining the training outcome.



**Figure 1.4. Training Process.** (Modified from Impellizzeri<sup>23</sup>)

*Heart Rate.* Another way in which internal load is routinely measured is via heart rate (HR) monitoring. This is routinely conducted through the use of HR devices that are worn during exercise to measure the intensity of the workload placed on the cardiovascular system. Some measure HR during exercise, while others focus on HR at

rest (RHR), or day to day commonly known as heart rate variability (HRV). The concept behind measuring HRV is that the autonomic nervous system controls heart rate, and the sympathetic nervous system and peripheral nervous system influence time between heart beats.<sup>14</sup> Therefore, measuring HR and the R to R interval, indirectly measures the autonomic nervous system and changes in fitness. Due to the physiological response that occur with training, numerous studies have measured and examined HR variability in soccer.<sup>14,107</sup>

Another way to monitor HRV is by examining HR percentage, and training time spent in each HR zone. Owen et al.<sup>13</sup> examined HR during training and match during high intensity (T-VH), and training in very high intensity (T-VHI), where T-VH was 85%-90% of the individual's maximum heart rate (HRmax) and T-VHI were defined at training  $\geq 90\%$  of HRmax. Significant correlations were found between training injury incidence for T-HI, but not for match injury incidence and training intensity.<sup>13</sup> This study was the first reported to examine HR percentage and injury incidence in soccer. Though percentage of HRmax is widely used, an examination by Dellal et al.<sup>108</sup> concluded the best method of analyzing HR in soccer players was not through percentages of HRmax, but rather looking at heart rate reserve as the most reliable indicator due to the high variation in RHR.

#### **1.4 Quantifying External Load**

*Global Positioning Systems.* In addition to quantifying individual's internal stressors, there are additional methods of calculating external loads placed on the physiological system; one-way of doing so is through the use of GPS units. These

devices were originally created for military purposes, and has translated to sport.<sup>109</sup>

Global positioning system technology units are sold by various companies, and can be rather reasonably priced at \$139.99 for a Garmin Forerunner 15,<sup>110</sup> to a Catapult GPS unit of ~\$5,000.<sup>111</sup> Certain wearable devices are more useful depending on the sport.

Soccer is a multidimensional sport consisting of high-intensity running, jumping, sprinting, accelerations, decelerations, and quick change of direction. Global positioning system devices are able to capture athlete movements and quantify changes undetected by the human eye.<sup>109,112,113</sup> Furthermore, GPS devices can measure a multitude of parameters that can include: accelerations, decelerations, distance covered, velocity zones, peak speed, and player load to name a few.<sup>109,113–115</sup> The validity of GPS devices have been examined, with an increased level of error for both 1-Hz and 5-Hz units when running at higher speed and accelerations that exceed  $>25\text{km}\cdot\text{h}^{-1}$ , which is imperative to know when analyzing data for soccer players whose speeds can exceed that range.<sup>115</sup>

Table 1.7 portrays various methods and metrics of data collection for the purpose of athlete monitoring. These represent three ways people have selected to measure stressors involved in the sport of soccer that include internal load through training load, which takes into account the training duration, additionally heart rate, and external load through use of GPS devices.

**Table 1.7: Studies Utilizing forms of Athlete Monitoring to Examine Soccer Athletes.**

Study	Year	Training Load	Heart Rate	Global Positioning System
Coutts et al. <sup>102</sup>	2009	✓	✓	
Colby et al. <sup>40</sup>	2014			✓
Malone et al. <sup>118</sup>	2015	✓	✓	✓
Campos-Vazquez et al. <sup>120</sup>	2015	✓	✓	
Anderson et al. <sup>119</sup>	2015			✓
Fanchini et al. <sup>99</sup>	2015	✓	✓	
Torreño et al. <sup>12</sup>	2016		✓	✓

## 1.5 Predicting Injury and Time Loss

Injuries at the professional level not only have the potential to negatively affect a teams record, but also create a financial burden. It has been estimated that professional soccer teams lose approximately 10-30% of player payroll due to injuries, and the top four professional leagues in soccer lost an average of \$12.4 million per team in 2015 due to injuries. The use of data in soccer is becoming more prevalent at all levels, and the norm at the professional levels. Injury prediction is currently being recognized as one of the more critical aspects of sport. With an accurate injury prediction model, a professional sports team can save millions of dollars lost to an athlete that is required to miss a match due to an injury. There are currently no proven probability models or algorithms to predict and thus prevent sports related injuries, and therefore keeping these athletes on the field. For this reason, exercise scientists are becoming increasingly important not only at the professional, but also the collegiate level. Numerous studies exist that analyze player data through various mechanisms, and include the use of GPS devices,<sup>40,109,113</sup> HR devices,<sup>13,14,108,116,117</sup> blood biomarkers,<sup>103,118</sup> daily perceptual measures,<sup>94,98</sup> and so forth, with no confirmed consensus on which measures predict injury.

Intrinsic variables that have been collected include training load, perceptual measures, and HR. Training load has been reported as a form of athlete monitoring through the simple method of pen and paper, but there is no universal consensus on how to measure load, or even how to apply the data. Extrinsic variables to predict injury have included wearable devices. One study by Erhmann et al.<sup>44</sup> aimed to determine which GPS variables best predicted non-skeletal soft tissue injuries and found that a high new load and meters per minute should be considered when attempting to prevent musculoskeletal injuries. Wearable companies are currently advertising their devices for performance monitoring and injury prevention. Some studies have attempted to establish methods of injury prevention utilizing devices, but there is no universal evidence of wearable technology or programs that successfully prevent injury in the literature. At the current time it is still up to those with the experience in the field of sports medicine and analytics to apply the data and relate it to what the athlete is experiencing in an effort to make an educated decision regarding player health and safety.

Screening tools are additionally utilized as injury predictors but often are only a piece of the puzzle related to injury prediction. A systematic review that aimed to determine which screening tools were best to predict injuries in the lower extremity concluded for soccer that: hamstring flexibility was not a predictor of hamstring strains, <80% of hip adduction strength-to-abduction strength ratio were found to be a significant predictor of an adductor strain, and decreased range of motion of hip abduction was a predictor for groin injury.<sup>46</sup> Additionally, ankle range of motion did not predict ankle injuries, and hip flexibility was not determined as a predictive injury screening tool in soccer athletes. Findings from this review suggest that some

correlations can be made in regards to injury predictors when measuring range of motion and flexibility, but only in a select few anatomical locations, and cannot be used to generalize prediction for injuries in all locations.

Not only will an athlete experience TL due to injuries, but illness as well. Resting heart rate can be a valuable tool when detecting signs of overreaching, which can in turn lead to overtraining and staleness.<sup>119</sup> In addition to injuries and illness, an athlete may lose time in sport due to external factors outside of their control, and vary based on competition level. At the collegiate level, an athlete may lose time due to class schedule conflicts. It is unknown how much TL due to extrinsic factors affect an athlete's training and overall performance. Predicting TL in sport may be difficult, but knowing external factors that athletes may experience based on competition level can help predict TL. Athletic trainers may be essential in predicting the duration of TL due to injury. Time loss can have a negative impact on an athlete, team, and country when playing at professional levels. It can have monetary ramifications and match loss repercussions. Predicting TL for both injury and other factors such as illness is imperative, with special emphasis on elite sports.

## **1.6 Gaps in the Literature**

To date, the NCAA Injury Surveillance System is the largest athletic injury surveillance system at the collegiate level.<sup>69</sup> This system defined an athlete-exposure as “1 student-athlete participating in 1 practice or competition in which he or she was exposed to the possibility of athletic injury, regardless of the time associated with that participation.”<sup>69</sup> Limitations to calculating IRs when using this definition is that an

athlete that is exposed to a 30-minute practice session is counted similar to that of a 120 minute practice session, when, in theory, an athlete is at a higher risk of injury when exposed to longer sessions. This method of calculating IRs may inflate or deflate IRs when accounting for EHs. Future studies at the collegiate level should aim to report and record training session times to calculate IRs per 1000 EHs. Additionally, AEs are limited to training sessions on the field, and do not often include all training taken place. Athlete exposures are currently being measured during practice and match. This definition of an exposure does not take into consideration the duration of the exposure. An athlete at the collegiate setting will be exposed to practice sessions, match settings, and presumably S&C sessions. The NCAA does not currently calculate out S&C training as a separate entity of AE. While S&C aims to prevent injury, an athlete is exposed to injury.

To our knowledge, there are no studies that predict injury and TL in sport through any form of athlete monitoring. Several studies have attempted to predict soft tissue injuries utilizing training load, GPS, and HR measurements, with some to little accomplishment. Nassis and Gabbett<sup>120</sup> published an editorial in 2016 calling for a consensus meeting in order to determine best evidence-based recommendations in regards to monitoring soccer athletes as there is still no consensus on monitoring loads, in an effort to optimize performance and reduce injuries.

Given the various modes of reporting injuries, it is imperative that injury research continues to occur but in a more unified fashion in soccer, as well as other sports. It is suggested that athlete EHs be the method of choice for the following reasons: 1) provides a more accurate representation of IRs, 2) has a lower chance of over



or under inflating IRs as seen when using AEs, and 3) takes into account the length of exposure, which is especially crucial when accounting for IRs during a match.

Furthermore, we need to continue to examine the common predictors resulting in injury, and they need to include everything from perceptual data to technologically advanced monitoring and tracking of both internal and external markers of stress.

CHAPTER II: An Examination of Time Loss, Injury Rates, and Factors Associated with  
Injury in NCAA Division I Men's Soccer

## 2.1 Introduction

Soccer is the most popular sport in the world as it is played by 270 million people, or approximately 4% of the population.<sup>1</sup> Given the high participation rates, injuries in soccer are of great concern. Injuries are reported in a multitude of ways. Definition of injury varies by study, and differences exist on how injury rates (IR) are calculated.<sup>64,85</sup> A consensus statement published in 2006 by Fuller et al.<sup>80</sup> on injury definitions and data collection procedures for soccer, classified a time loss (TL) injury as: “an injury that results in a player being unable to take a full part in future football training or match play.” Injuries have also been reported by player position, playing year, and level.<sup>121</sup> There remains no consensus for reporting IR, which makes it difficult to compare across studies. Injury rates have been calculated per 1000 exposure hours (EH),<sup>85</sup> per 1000 athlete exposures (AE),<sup>5</sup> and further divided by season,<sup>63</sup> type of exposure,<sup>63</sup> and athlete playing position.<sup>66–68</sup>

Injury rates have the highest sensitivity when calculated per 1000 EH rather than per 1000 AE. The varying approaches to IR calculation make it difficult to compare IR between studies. Since 1988, the National Collegiate Athletic Association (NCAA) Injury Surveillance System has reported IRs per 1000 AE in each sport.<sup>5</sup> Two areas not accounted for using this method of reporting are as follows: 1) AE are only being measured in practices and matches and 2) the reporting of raw AEs can inflate the actual rate of injury by providing an exposure when an athlete may only have participated in half a training session, or a few minutes of a match. Both of these shortcomings need to be explored because it is well known that strength and conditioning (S&C) sessions are a significant amount of the time required by NCAA athletes, however, these training

exposures may not routinely be included in these calculations. Additionally, when examining IR per 1000 AE rather than per 1000 EH, IR by AE can give a false sense of IR, which can in turn bias clinicians and coaches. Furthermore, two areas associated with the topic of IRs are TL due to injury and injury predictors.

Closely tied to IR, or perhaps of greater concern to coaches and administration, is TL. Time loss is when an athlete cannot participate in their sport during a mandatory training session held by a member of the coaching staff, and can be essential to note at higher competition levels. Time loss has been examined when analyzing TL vs. non-TL injuries as presented by Powell and Dompier;<sup>122,123</sup> IR were compared among the two groupings and found that in NCAA male soccer athletes, a combined IR was 23.5 injuries per 1000 AEs, where TL injuries only accounted for 7.1 injuries per 1000 AEs. Studies have examined TL due to injury alone, but exclude additional reasons for TL, which can impact athletes EH. Additional reasons for TL include illness, appointments, travel schedules, and so forth. Additionally, TL at the collegiate level often occurs for athletes due to academics, which can consistently impact an athlete through under-exposure to training. Currently, little research exists quantifying the TL and predictors of injury,<sup>45,47,124</sup> which is why it is imperative to continue to examine these variables so that in the future we may be able to minimize TL and identify areas associated with injury. Time loss has potential to influence IR in the sense that an athlete would be undertrained, and not prepared for the impending training load. Therefore, research is needed to examine TL, not only for the purpose of calculating IR per EH, but to analyze additional factors that could contribute to the IR.

Another rather important area of research that has the potential to influence IR in soccer is through athlete monitoring. Researchers have studied physical load,<sup>40,109,125</sup> internal physiological measures,<sup>13,108,117</sup> and video analysis. Dellal et al.<sup>108</sup> concluded the best method of analyzing heart rate in soccer players was not through percentages of heart rate (HR) max, but rather examine HR reserve as the most reliable indicator due to the high variation in a teams resting HR. Numerous studies exist analyzing player data through various mechanisms including the use of GPS devices,<sup>40,109,113</sup> HR devices,<sup>107</sup> blood biomarkers,<sup>103,118</sup> and daily perceptual measures,<sup>94,98</sup> with no consensus on which measures predict injury. One example of a study that attempted to examine the relationship of physiological variables (i.e. HR and training load) to IR was by Mallo and Dellal<sup>68</sup> who examined the incidence of muscle strains per 1000 EHs to mean HR ( $r^2=0.5041$ ). Owen et al.<sup>13</sup> examined HR during training and match play, and found correlations between training injury incidence while training at a very-high intensity, but not for match injury incidence and training intensity. This suggests that injury incidence utilizing HR should be further examined for training, but not as essential during a match. Utilizing GPS devices, Erhmann et al.<sup>44</sup> aimed to determine which variables best predicted non-skeletal soft tissue injuries, and found high new load and meters per minute should be considered when aiming to prevent musculoskeletal injuries. When examining work load in a general sense, Gabbett et al.<sup>126</sup> proposed examining acute-to-chronic workload, and reported that an increase of >10% in workload from the prior week has the potential to increase an athletes risk of injury. Despite these findings, no study has successfully predicted injury, and therefore research must continue to closely analyze and interpret both internal and external load over time to best predict injury.

However, before we can accomplish this task, we must closely analyze those athletes that present with injuries. Thus, our aims are to explore associations between injuries and variables that may have attributed to injury. Additionally, our purpose is to quantify exposure time in all areas that include formal practice held by the coaches, S&C sessions, matches, any additional tests and events mandated by the coaches, and compare to reported rates.

## **2.11 Purpose of Study**

The purpose of this study is three-fold: 1) To compare IRs, mechanisms, and location of injury to previously reported data conducted by the NCAA and to present an alternative model for the quantification of IRs, 2) To quantify TL over the course of the competitive season and to describe the specific reasons for TL, and 3) To present a case series of frequently injured players and explore commonalties within each for both measures of internal and external stress over the course of the competitive season with the hopes of improving future predictive modeling.

## **2.2 Methods**

### **2.21 Participants**

NCAA Division I male soccer players participated in a yearlong observational field study. Participants were included in the study if they were between 18-30 years of age, and were active members participating on the Division I Men's Soccer Team during the 2015 season. Screening was performed via medical history questionnaires to ensure that the participants were: a) a current member of the University men's soccer team participating in the 2015 season, b) between the ages of 18-30 years, c) cleared by the

University's sports medicine department and passed their pre-participation physical examination. Participants were excluded from the study if they officially left the team for any reason from the start of the study. Thirty-four participants agreed to be involved in the study and were informed by the researchers participation in the study was entirely voluntary. The participants signed an informed consent form approved by the University of Connecticut Institutional Review Board. Participants were informed they could terminate participating in the study at any time.

## **2.22 Procedures**

Age (yrs), playing position, height (cm), body mass (kg), body fat (%) were collected at baseline in August. Height was measured using a standard measuring tape and recorded to the nearest centimeter. Body mass was taken on a standard scale and recorded to the nearest .01 kg (Ohaus, Defender 5000, Pine Brook, NJ). Body fat percentage was measured using skinfold calipers (Lange Skinfold Caliper, Beta Technology, Santa Cruz-California) using the 4-site Durnin and Womersley method at the following locations: bicep, tricep, subscapular, and suprailiac,<sup>127</sup> and calculated using the following equation:

$$\text{Body Fat \%} = (495/1.1631 - (0.0632 \times \text{LOG}(\text{Bicep} + \text{Tricep} + \text{Subscapular} + \text{Suprailiac}))) - 450$$

Aerobic fitness was determined both in the field and in the laboratory. Field testing included the Yo-Yo intermittent recovery level 1 (Yo-Yo IR1) test which estimated each individuals ability to perform repeated intense exercise to test the aerobic system.<sup>26</sup> The test performed included a 2x20m shuttle run with increasing speeds, interspersed with a 10-second period of active recovery that was controlled by audio

signals from an audio file and speakers. Participants ran until they were unable to maintain the speed, from which the total distance covered was recorded. Total distance for the test if completed was 3600m. The participants Yo-Yo IR1 distance was applied to the following formula by Bangsbo et al.<sup>26</sup> to estimate each participant's VO<sub>2</sub>max:

$$\text{VO}_2\text{max (ml}\cdot\text{kg}\cdot\text{min}^{-1}) = \text{IR1 distance (m)} \times 0.0084 + 36.4$$

The laboratory VO<sub>2</sub>max test was conducted on a motorized treadmill (Precor, Woodinville, WA) at a 1% grade. Expired gases were collected using a metabolic cart (ParvoMedics, True One 2400, Sandy, Utah). Each stage was 2 minutes in length and speed was increased 0.8-1.6 kmh per stage depending on respiratory exchange ratio measurements observed during stage 1 or 2. This was done to ensure that participants completed the entire test within 8-12 minutes as not to induce muscular fatigue.

### **Training, Match, and Strength & Conditioning Monitoring Methods**

Participant EH, status, and duration were obtained for all events throughout the year. Prior to each session (formal practice, summer S&C, and matches) participants were provided with a personalized GPS unit: either L3 or S4 (MinimaxX, Team 2.5, Catapult Innovations, Scoresby Australia) and vest that held the device in place between the participants' shoulder blades. All data during trainings and matches were collected and imported into the Catapult Sprint 6.0 (Catapult Innovations, Scoresby, Australia) software. Session time, date, HR, GPS, playing status, and injury data were collected from each training and match. Heart rate data were obtained using both Polar Team and Polar Team<sup>2</sup> Pro (Polar Electro Oy, Kempele, Finland) devices. Straps were worn around the chest with the device located below the sternum. Heart rate data were uploaded following the sessions and downloaded using Polar Software.



The study was divided into five phases. These same phases reflect those defined by Dick et al.<sup>69</sup> referred by the NCAA (Table 2.11).

**Table 2.11: Study Phase, Training Season, and Associated Dates.**

Phase	Season	Dates
1	Offseason	01/19/2015 - 04/23/2015
2	Summer	04/24/2015 - 08/11/2015
3	Preseason	08/12/2015 - 08/27/2015
4	In-Season	08/28/2015 - 10/31/2015
5	Postseason	11/01/2015 - 11/22/2015

Measurements collected for training sessions were similar to those of match competitions and included: number of athletes exposed, individual duration time, and athlete status (Table 2.13). Data collected from S&C included training duration, number of athletes exposed, and player status.

## 2.23 Outcome Measures

**Table 2.12: Operational Soccer Terminology.**

Term	Definition
Formal Practice	team-based and individual physical activities under the control or guidance of the team's coaching or fitness staff that are aimed at maintaining or improving players' football skills or physical condition. <sup>80</sup>
Strength & Conditioning (S&C)	training held, or created, by the strength and conditioning coach for the purpose of strength, power, and/or resistance training.
Match Exposure	a match, or game, that is played between teams of different clubs <sup>80</sup>
Preseason	all formal team practices and exhibition matches conducted before the first regular season contest. <sup>69</sup>
In-season	also called “regular season,” all practices and competitions from the first regular season competition through the last regular season competition. <sup>69</sup>
Postseason	all practices and competitions after the last regular season competition through the last postseason competition. <sup>69</sup>
Offseason	the time after postseason during the spring academic semester.
Summer	the time after the offseason, and prior to preseason.

Time loss data were collected from AE and athlete EHs (see Table 2.13). Time loss was calculated for all members in the study during: formal practice, S&C, and

matches, and were calculated for all phases, excluding summer (Table 2.14). Summer data were not included as training sessions were provided as an optional service, and not mandated. A TL was provided to an athlete if: 1) they were unable to participate in 100% of each training session in the 4 phases, 2) they were unable to participate in a match due to injury, or 3) they were unable to participate in 100% of S&C during the offseason. Time loss was classified into 5 sub-categories: injury, illness, academic, coach initiated modification, and other. Coach initiated modifications were counted from coach initiated rest and physical rest, which were for reasons that did not include documented injury. Other category were classified as TL due to various reasons from absent status. Odds of TL were calculated for each category, and further compared to preseason. Odds were calculated as follows:

$$\sum (\text{sub-category}) \text{ by (season)} / \sum (\text{sub-category}) \text{ for 2015} = \text{odds TL (sub-category)}$$

**Table 2.13: Operational Player Status Terminology.**

Term	Definition
Time Loss (TL)	time loss was counted for an athlete if they did not participate in a team organized session.
Athlete Exposure (AE)	1 student-athlete participating in 1 practice or competition in which he or she was exposed to the possibility of athletic injury, regardless of time associated with that participation. <sup>69</sup>
Exposure Hour (EH)	time that an individual spent training (i.e. formal practice, S&C, match).
Full Participation	an athlete was able to participate in the entire training session.
Absent	an athlete who did not participate in a mandatory training or match due to unknown or other reasons.
Academic	an athlete who did not participate in a mandatory training or match due to academic reasons.
Illness	the status provided to an athlete that could not participate in a mandatory training session or match due to a known illness by the health care professionals.
Injured	the status provided to an athlete that could not participate due to an injury (see injury definition Table 2.11).
Physical Rest	the status provided to an athlete who could not participate due to a physical

	complaint that prevented them from participating.
Coach Initiated Rest	the status provided to an athlete who did not participate in a training session because he was sat out by the head soccer coach.
Recovery day	the status provided to an athlete for an off day that was dedicated to allow the athletes complete rest from all training.
Limited participation	the status provided to an athlete who was unable to participate fully in a mandatory training or match due to an injury or physical complaint.

Table 2.12 include injury definitions that were used for this study based off previously reported studies that analyzed IR.<sup>69</sup> Data were collected from the sports medicine staff and athletic training staff that accessed participants medical history. Injury data were provided by the sports medicine staff for all TL injuries. Injury data included: date of injury, diagnosis, region and location of injury,<sup>80</sup> and body part<sup>5</sup> (head/neck, upper extremity, trunk/back, lower extremity, other/system). Injury rates were calculated based off exposure and season during the offseason, preseason, in-season, and postseason.<sup>128</sup> Modifications were recorded by the researcher during all phases of training.

**Table 2.14: Operational Injury Terminology.**

Term	Definition
Injury	(a) occurring in a scheduled competition or training; (b) requiring medical attention or checking by a professional such as an athletic trainer, doctor or physiotherapist; and (c) resulting in the player being restricted from normal participation for one or more days. <sup>53,129</sup>
Minimal Injury	1-3 days <sup>58</sup> of time loss associated with training or match.
Mild Injury	4-7days <sup>58</sup> of time loss associated with training and match play.
Moderate Injury	8-28 days <sup>58</sup> of time loss associated with training and match play.
Severe Injury	>28 days <sup>58</sup> of time loss associated with training and match play.
Injury Rate (IR)	number of injuries per 1,000 EHs [ $(\sum \text{injuries} / \sum \text{EHs}) \times 1,000$ ]. <sup>58</sup> number of injuries per 1,000 AE [ $(\sum \text{injuries} / \sum \text{AE}) \times 1,000$ ]. <sup>5</sup>

Athlete Exposure: AE; Exposure Hour: EH

Injury rates were presented in one of two ways: 1) Per 1000 EHs and 2) Per 1000 AE, and were calculated for all members in the study during: formal practice, S&C, and matches. Exposure hours were defined as the total time that each individual started and completed each session. Furthermore, AE data were calculated for each phase of the study for all participants.

Injury severity was calculated as percentage of total injuries by minimal, mild, moderate, and severe injuries defined in Table 2.14. Injury mechanism was examined by: contact, non-contact, contact with ball, contact with surface, and other. Injury type and location was calculated utilizing Fuller et al.<sup>80</sup> 7-injury categories and 14 sub-categories, and further divided by exposure setting (formal practice, S&C, and match).

### **Internal Training Load and External Training Load**

Internal load was calculated using HR training zones, and training impulse (TRIMP) while external load was calculated using Player Load™ (PL). Each participant's HR zones were divided into eight zones based on their RHR and MHR. Maximum HR was determined one of two ways either maximum obtained during the VO<sub>2</sub>max test or Yo-Yo IR1. Resting heart rate was collected in the morning, where the athletes were required to rest on with HR monitors on for a set protocol of 10-minutes in August. Heart rate data was measured at each formal practice, S&C during summer, and matches by 28 field players. The HR data were examined by HR reserve (HRres) at 85-100%. Heart rate reserve was calculated as follows:

$$\text{HRres} = (\text{MeanHR} - \text{RHR}) / (\text{MHR} - \text{RHR})$$

TRIMP was calculated from the HRres data-using individual training mean HR, which included their RHR, MHR and training duration as follows:

$$\text{TRIMP} = (\text{HRres}) * (\text{Duration}) * 0.64^{1.92 * (\text{HRres})}$$

External load for all sessions and matches were measured utilizing Catapult MinimaxX GPS (Catapult Innovations, Melbourne, Australia). Player Load<sup>TM</sup> is an algorithm created within the Catapult program utilizing the following formula:

$$\text{Player Load} = \sqrt{(\text{fwd}_{t=i+1} - \text{fwd}_{t=i})^2 + (\text{side}_{t=i+1} - \text{side}_{t=i})^2 + (\text{up}_{t=i+1} - \text{up}_{t=i})^2}$$

Where fwd = forward acceleration, side = sideways acceleration, up = upward acceleration and t = time. Player Load<sup>TM</sup> data was used to measure external stressors placed on the participants, and was measured at each formal practice, S&C during summer, and matches by 28 field players.

## **Injury Prediction**

Data for injury prediction included measurements suspected to correlate to any of the TL injuries seen during the 2015 year based off prior injury knowledge and soccer studies.<sup>13,44,58,66</sup> The sample size for injury prediction data excluded goalies (n=28) as goalies did not wear GPS and HR monitoring devices. Data included in the analysis consisted of: past medical history, type of exposure, EHs, soccer season, place of injury, player status, age, match congestion, playing year, fatigue, muscle soreness, rate of perceived exertion, training load, Player Load<sup>TM</sup>, HRres percentages and TRIMP.

*Case Studies.* Exposure minutes demonstrate all modifications; PL and HR demonstrate modifications during trainings and matches where the devices were worn.

Summer training data were excluded when calculating for the mean and SDs; the data did not capture all forms of training as the athletes performed pick up soccer during the evenings, which were not quantified. Case 3 PL excluded postseason ending injury data to be included to calculate the mean and SD as this athlete was never fully cleared to play by the ATC during the 2015 calendar year. Modifications were displayed in the graphs for the trainings when GPS and HR devices were worn. Missing PL data were replaced using predictive mean matching via multiple imputation by chain equations packages.<sup>130</sup>

## **2.3 Statistical Analyses**

Mean differences were found when comparing IR per 1000 AE to the NCAA. Injury rates were calculated and adjusted per 1000 AEs, and per 1000 EHs. We had planned to run multiple regressions for the injury prediction, but were underpowered due to the low number of team injuries, and 41% of field player injuries that occurred in 4 individuals. Data were expressed as mean  $\pm$  standard deviation (SD), and percentages where relevant (M  $\pm$  SD [95% CI]).

## **2.4 Results**

### **2.41 Demographics**

Participant characteristics were as follows: age, 20 $\pm$ 2yrs; height, 181 $\pm$ 6.1cm; body mass, 80.2 $\pm$ 7.88kg; body fat, 12.8 $\pm$ 2.8%; VO<sub>2</sub>max, 52.4 $\pm$ 5.16 ml $\cdot$ kg $\cdot$ min<sup>-1</sup>; Yo-Yo IR1 estimated VO<sub>2</sub>max, 61.6 $\pm$ 4.21 ml $\cdot$ kg $\cdot$ min<sup>-1</sup>; Yo-Yo IR1 Distance, 3002 $\pm$ 500.6m.

## 2.42 Time Loss

*Time Loss.* Reasons for TL were divided into five categories where 4.2% attributed from coach initiated modification, 4.6% from illness, 12.1% due to other reasons, 18.8% attributed from academic, and 60.3% due to injury. Time loss was seen least during preseason with an overall TL of 2.8%, and most during postseason with 14.4% TL. The odds of TL are displayed in Table 2.21 for all phases, excluding summer. The odds of TL when compared to preseason due to injury were 19-fold greater during the in-season and 18-fold greater during the postseason. Additionally, in-season had greater odds of TL at 13x higher when compared to preseason for both academic and “other.” Illness was 16x greater during the postseason.

Table 2.21 Odds of Time Loss over the Course of an Academic Training Year

Season	Injury	Illness	Academic	Coach Initiated Modification	Other
Offseason	0.58	3.63	0.33	0.16	0.34
Preseason	0.03	0.22	0.05	1.16	0.06
In Season	0.61	0.00	0.63	0.31	0.72
Post Season	0.29	0.04	0.46	0.10	0.38
2015	0.81	0.16	0.16	0.03	0.10

When examining injury TL, the least amount of TL was during preseason at 0.8%, and most during postseason at 9.7%. Illness TL were greatest during the offseason at 0.6%, and had a 0% TL during the in-season. Academic TL was greatest in postseason with 4.3%, and least in preseason (0.4%). Additional reasons for TL classified in the “other” category were highest during postseason at 2.4%, and least during preseason 0.3%.

Figure 2.22 displays TL hours per season by 5 categories.

**Table 2.22 Time Loss Hours By Season**

Category	Offseason	Preseason	In Season	Postseason	2015
Injury	96.4	8.2	99.1	58.8	262.5
Illness	15.7	3.7	0.0	0.7	20.1
Academic	20.5	3.9	31.8	25.8	81.9
Coach Initiated Modification	2.6	9.9	4.3	1.6	18.5
Other	13.4	2.9	22.2	14.5	52.9
Total Time Loss	148.6	28.5	157.4	101.4	436.0
Total Exposure Hours	2579.4	980.4	2020.3	603.5	6183.6

## 2.43 Injury

*Injury Rates & Exposures.* Overall IR in 2015 were 4.6 injuries per 1000 EH and 5.6 injuries per 1000 AE. Seasonal EH, AE, and IR are presented in Table 2.23.

Combined team training EHs for all phases were 6515.2 hrs and matches were 506.0 hrs for all 34 participants in the study.

**Table 2.23 Exposure Hours, Athlete Exposures, and Injury Rates per Season**

Season	Exposure Hours				Athlete Exposures			
	Formal Practice	S&C	Match	IR	Formal Practice	S&C	Match	IR
Off Season	1709.26	746.25	85.52	5.1	1087	944	55	6.2
Summer	26.80	825.05	0.00	-	20	671	0	-
Preseason	944.39	3.00	33.00	3.1	571	6	22	5.0
In Season	1662.32	90.55	301.32	6.4	1515	117	197	7.1
Post Season	506.68	0.88	86.17	5.1	479	2	55	5.6
2015	4849.45	1665.73	506.01	4.6	3672	1740	329	5.6

Injury rates were further divided by season (offseason, preseason, in-season, and postseason) by exposure type (formal practice, S&C, and match) and presented per 1000 EH and per 1000 AE. Mean differences were found when comparing AE rates and EH rates with greatest differences seen in preseason match rates (-10.6), in-season match (7.3), offseason match (3.2), formal practice (1.7), and postseason match (4.2).

**Table 2.24: Exposure Hour Injury Rates per 1000 EHs**

Season	Formal Practice	S&C	Combined Training	Match
Off Season	2.9	4.0	3.3	46.8
Preseason	1.1	0.0	1.1	60.6
In Season	1.8	0.0	1.7	33.2
Post Season	2.0	0.0	2.0	23.2
2015	2.1	2.3	2.1	35.6

EH: Exposure Hours

**Table 2.25 Athlete Exposure Injury Rates per 1000 AEs**

Season	Formal Practice	S&C	Combined Training	Match
Off Season	4.6	3.2	3.9	50.0
Preseason	1.8	0.0	1.7	50.0
In Season	2.0	0.0	1.8	40.5
Post Season	2.1	0.0	2.1	27.4
2015	2.7	4.2	2.6	40.9

AE: Athlete Exposures



When compared to the NCAA,<sup>5</sup> IR calculated per 1000 AE were lower in training during preseason (1.7 vs. 8.1), and in-season (1.8 vs. 2.8), while higher for postseason (2.1 vs. 1.9). Match IR were higher in all seasons: preseason (50.0 vs. 21.3), in-season (40.5 vs. 22.3), and postseason (27.4 vs. 16.28).

*Injury Severity.* Injury severity was calculated for all TL injuries that occurred during the offseason, preseason, in-season, and postseason. Of the injuries, 22% were classified minimal (1-3 days missed), 39% mild (4-7 days missed), 16% moderate (8-28 days missed), and 23% severe (>28 days lost). Of the TL injuries, 39% occurred during the offseason, 3% in summer, 9% from preseason, 39% during in-season, and 10% in postseason. Furthermore, 12.9% were re-injuries, 22.6% were injuries to the same region in 2015, and 54.8% were re-injuries to the same region at any point in their life.

*Injury Mechanism.* The mechanism of injury were analyzed for all injuries. Non-contact injuries accounted for 54.8% of overall injuries, followed by contact/collision with another player (32.3%), contact with the ball (3.2%), contact with surface (3.2%), and other (3.2%).

*Injury Type and Location.* Analysis found that 55% of injuries occurred during a soccer match, 32% in formal practice, and 13% during S&C. Table 2.26 represents injury percentage by exposure, and utilizes Fuller et al.<sup>80</sup> injury groups and categories. Injuries during S&C were in the muscle/tendon category 100% of the time, and occurred in this group 45.2% of overall injuries.

**Table 2.26: Percentage of Overall Injuries by Grouping, and Exposure in a DI Men's Soccer Team**

Main Grouping	Category	Formal Practice (10)	Match (17)	S&C (4)	Combined
Total	All injuries	32.0%	55.0%	13.0%	100.0%
Fractures and bone stress	Fracture	0.0%	6.5%	0.0%	6.5%
	Other bone injury	0.0%	3.2%	0.0%	3.2%
Joint (non-bone) and ligament	Dislocation/ subluxation	0.0%	0.0%	0.0%	0.0%
	Sprain/ligament injury	9.4%	9.4%	0.0%	18.8%
	Lesion of meniscus or cartilage	0.0%	3.2%	0.0%	3.2%
Muscle and tendon	Muscle rupture/ tear/ strain/ cramps	16.1%	9.7%	9.7%	35.5%
	Tendon injury/ rupture/ tendinitis/ bursitis	3.2%	3.2%	3.2%	9.7%
Contusions	Haematoma/ contusion/ bruise	3.2%	6.5%	0.0%	9.7%
Laceration and skin lesions	Abrasion	0.0%	0.0%	0.0%	0.0%
	Laceration	0.0%	0.0%	0.0%	0.0%
CNS/PNS	Concussion	0.0%	9.7%	0.0%	9.7%
	Nerve injury	0.0%	0.0%	0.0%	0.0%
Other	Dental injury	0.0%	0.0%	0.0%	0.0%
	Other injury	0.0%	3.2%	0.0%	3.2%

The location of injuries found for this Division I Men's Soccer team were similar to those reported by the NCAA as seen in Table 2.27. Greatest differences were observed in injuries occurring to the head, face, and neck with 22.6% of the injuries for this soccer team, and 9.8% for the NCAA. Additionally, there were fewer TL torso and pelvis region for this Division I team at 3.2%, to the NCAA percentages of 14.7%.

**Table 2.27: Location of Injury Comparisons in 1 DI Soccer Team vs. all NCAA Men's Soccer**

Location	DI Soccer Team (n=34)	NCAA Soccer (n=21,601)	Mean Difference
Head/Neck	22.6%	9.8%	-12.8%
UE	3.2%	6.2%	3.0%
Trunk/back	3.2%	14.7%	11.5%
LE	74.2%	65.6%	-8.6%
Other/system	0.0%	3.7%	3.7%

NCAA: National Collegiate Athletic Association

## 2.44 Case Studies

*Injury Prediction.* When analyzing data collected for our injury prediction model, we found we were underpowered. Therefore, we continued to use the data collected for the model to display 4 case series. Table 2.28 displays variations from the 4 most commonly injured athletes to the rest of the team.

**Table 2.28: Descriptives of 4 Commonly Injured DI Athletes vs. DI Soccer Team.**

	Injured (n=4)	Team (n~30)
Match Exposure Hours	18.62%†	81.38%
Exposure Hours	208†	191
Average Number of Injuries	4§	1
Head Injuries (%)	60%	40%
Overall Team Injuries (%)	44.40%	55.60%
VO <sub>2max</sub> (ml·kg·min <sup>-1</sup> )	57*§	52
Team Season Ending Injuries (%)	40%	60%
Year Ave. PL % Difference from Team (Values provided for Team (au))	-0.75%	-
Year Ave. TL % Difference from Team (Values provided for Team (au))	-6.79%	-
Year Ave. TRIMP % Difference from Team (Values provided for Team (au))	0.50%	-
Year Ave. HRres 85-100% % Difference from Team (Values provided for Team (%))	11.29%	-

PL: Player Load; TL: Training Load; HRres: Heart Rate Reserve. Negative number denotes higher value.

†Indicates > Team Mean

§Indicates >1 SD Team Mean

\*Indicates exclusion of athlete due to injury.

*Case Studies.* Four individual athletes were examined for exposure minutes (EM), PL, TRIMP, and HRres, which are demonstrated in Figures 3.1-3.43. Table 2.29 represents the mean and standard deviations for each case, and the number of times each case exceeded 1 SD from the mean.

**Table 2.29: Athlete Monitoring in 4 Case Studies over the Course of 2015.**

Case	Exposure Minutes		Player Load™		TRIMP		HRres	
	(mins)	(+1) SD	(au)	(+1) SD	(au)	(+1) SD	(85-100%)	(+1) SD
1	105±43	19	642±278	17	111±56	15	4±6	13
2	114±44	24	600±273	20	128±73	29	8±12	15
3	119±44	12	672±220	12	150±66	11	14±13	12
4	96±42	19	500±217	10	143±71	11	18±16	18

Mean±SD.

## Exposure Minutes.

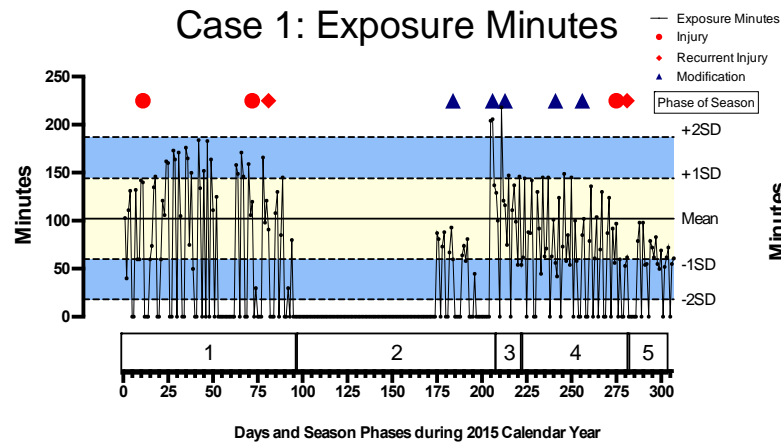


Figure 2.11. Exposure Minutes for Formal Practice, S&C Sessions, and Matches in 2015 for C1.

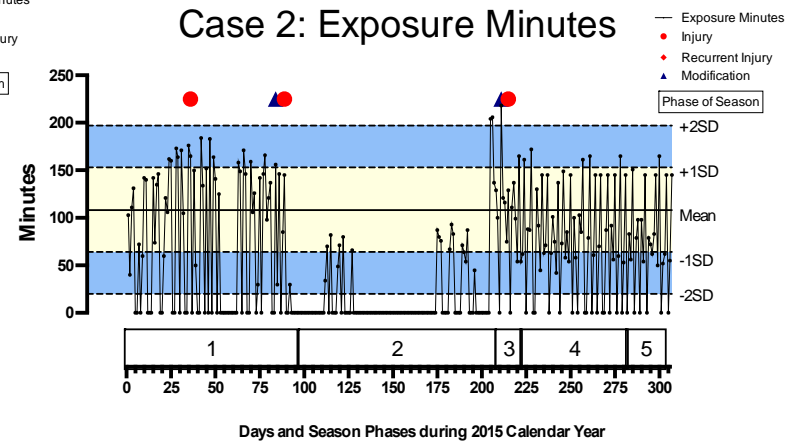


Figure 2.12. Exposure Minutes for Formal Practice, S&C Sessions, and Matches in 2015 for C2.

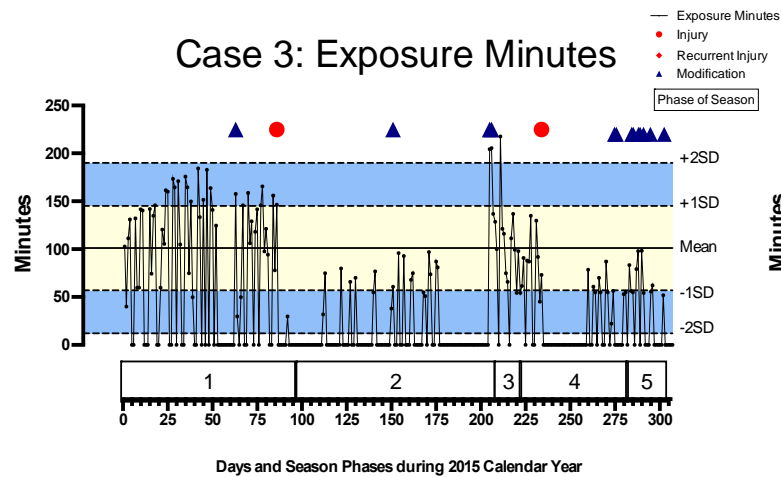


Figure 2.13. Exposure Minutes for Formal Practice, S&C Sessions, and Matches in 2015 for C3.

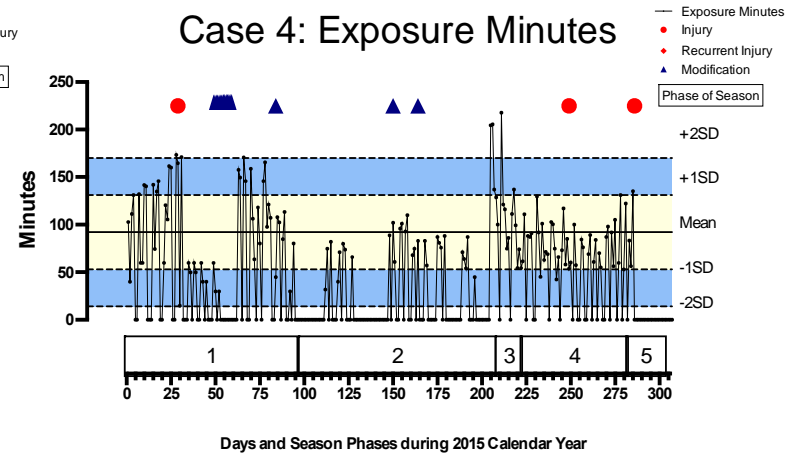


Figure 2.14. Exposure Minutes for Formal Practice, S&C Sessions, and Matches in 2015 for C4.

## Player Load™.

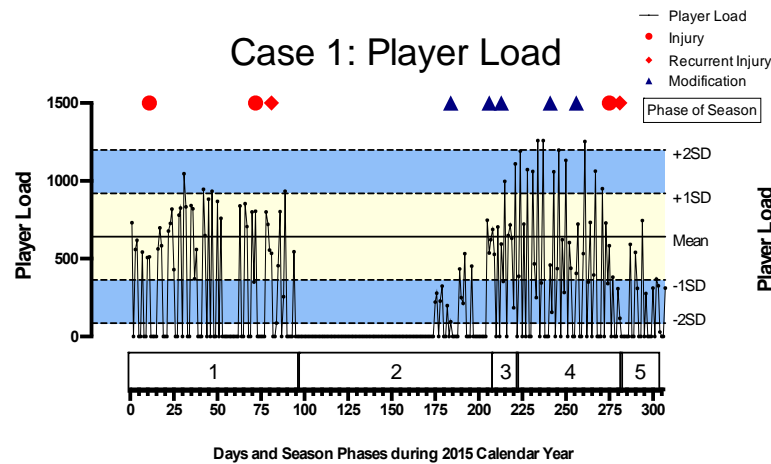


Figure 2.21. Player Load™ for Formal Practice, S&C Sessions, and Matches in 2015 for C1.

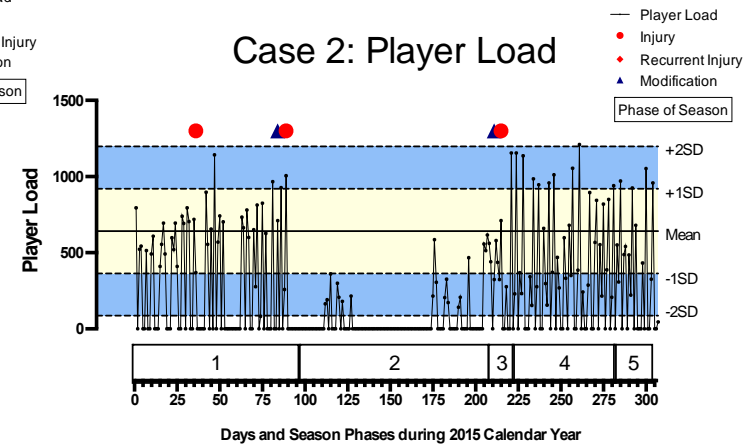


Figure 2.22. Player Load™ for Formal Practice, S&C Sessions, and Matches in 2015 for C2.

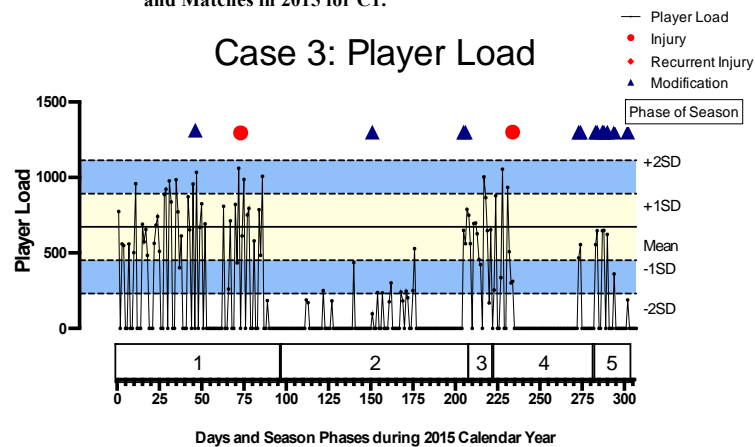


Figure 2.23. Player Load™ for Formal Practice, S&C Sessions, and Matches in 2015 for C3.

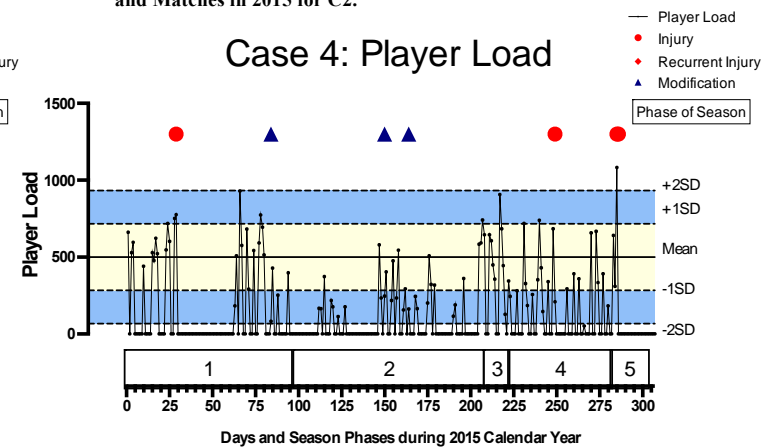


Figure 2.24. Player Load™ for Formal Practice, S&C Sessions, and Matches in 2015 for C4.

## Training Impulse (TRIMP).

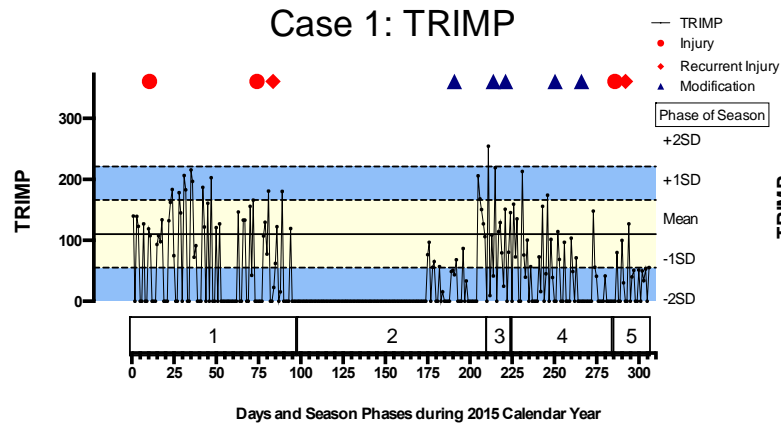


Figure 2.31. Training Impulse for Formal Practice, S&C Sessions, and Matches in 2015 for C1.

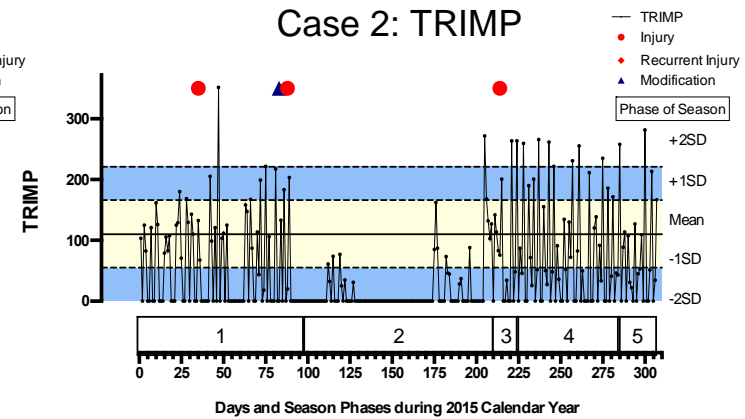


Figure 2.32. Training Impulse for Formal Practice, S&C Sessions, and Matches in 2015 for C2.

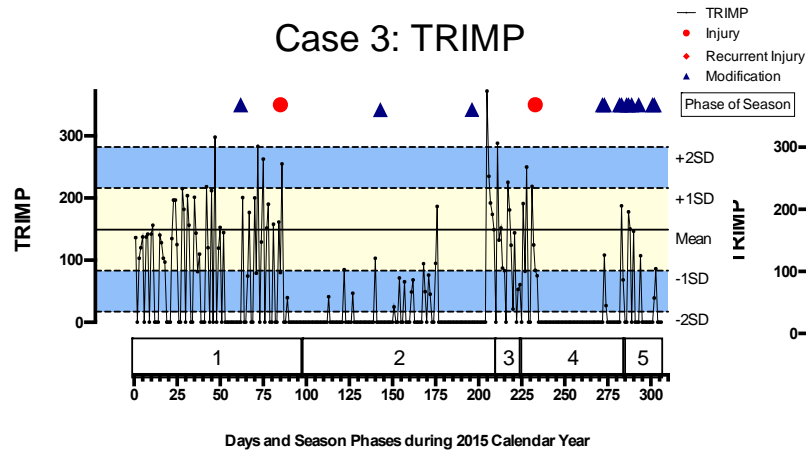


Figure 2.33. Training Impulse for Formal Practice, S&C Sessions, and Matches in 2015 for C3.

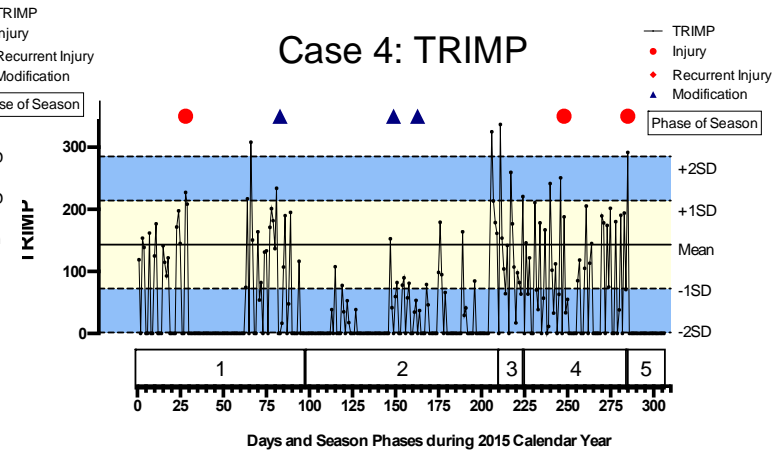


Figure 2.34. Training Impulse for Formal Practice, S&C Sessions, and Matches in 2015 for C4.

Heart Rate Reserve (HRres 85-100%).

Case 1: Duration in High Intensity HR Zone

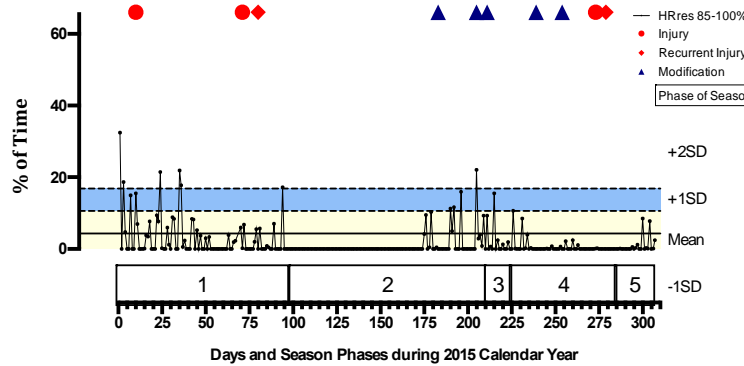


Figure 2.41. Percentage of Time in High Intensity HR Zones (HRres 85-100%) during Formal Practice, S&C Sessions, and Matches for C1.

Case 2: Duration in High Intensity HR Zone

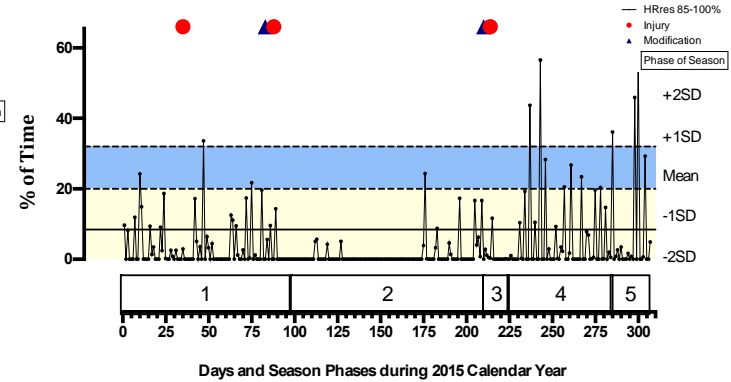


Figure 2.42. Percentage of Time in High Intensity HR Zones (HRres 85-100%) during Formal Practice, S&C Sessions, and Matches for C2.

Case 3: Duration in High Intensity HR Zone

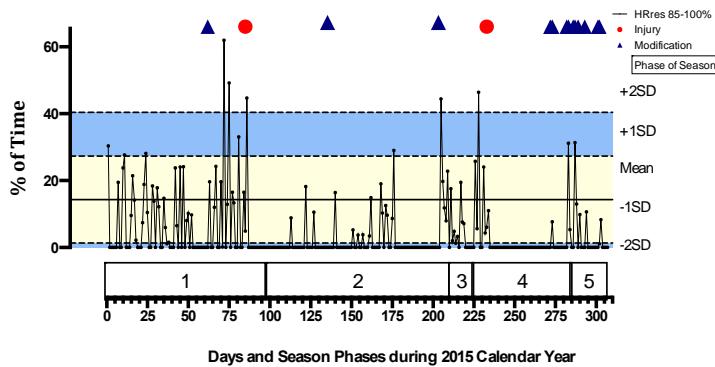


Figure 2.43. Percentage of Time in High Intensity HR Zones (HRres 85-100%) during Formal Practice, S&C Sessions, and Matches for C3.

Case 4: Duration in High Intensity HR Zone

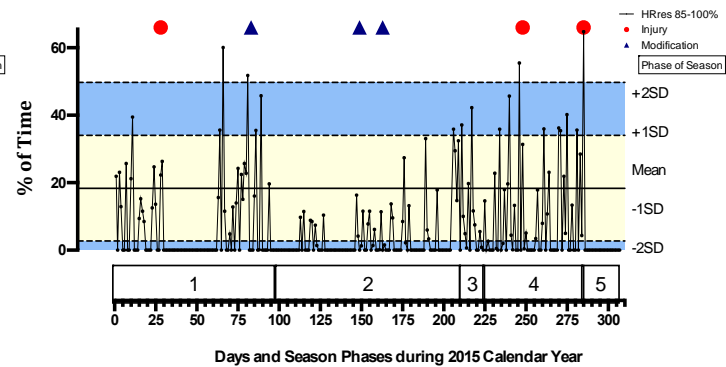


Figure 2.44. Percentage of Time in High Intensity HR Zones (HRres 85-100%) during Formal Practice, S&C Sessions, and Matches for C4.

## **2.5 Discussion**

The present study examined an NCAA Division I Men's Soccer team for the 2015 calendar year that included all seasons: offseason, summer, preseason, in-season, and postseason. To our knowledge, no study has examined reasons for TL that did not account for injury. Factors associated with TL can be attributed to IR, and additional measures that have the possibility of preventing injuries through athlete monitoring. Additionally, no study to our knowledge at the collegiate level has examined IRs during the offseason, nor separated training IR by training exposure (formal practice vs. S&C) in a collegiate soccer team. Furthermore, we discuss evidence comparing IR per 1000 EH versus IR per 1000 AE, and how IR per 1000 EH may be a more accurate way to track IRs.

### Time Loss.

In the present study, TL was quantified throughout 4 phases (offseason, preseason, in-season, and postseason) and categorized into 5 main groups where: injuries, illness, academic associations, coach initiated modification, and other were factors when examining reasons for TL. It is important to note none of the offseason injuries, or injuries that attributed to TL, were as a result of post-operative surgeries. Reasons for TL can be valuable to note when creating a training program for a team. Time loss is important not only in the broad sense of missing an entire session, but also in which part of training time is lost. For example, one athlete may have class during the first half of training every Tuesday and Thursday. If this athlete is required to perform at the same level as his teammates who have had proper warm-up, this individual may be at a higher risk of injury. This is the same as if a coach were to put a player into a match



after sitting on the bench with no warning or warm-up, and expect the athlete to perform their maximal velocity and accelerations. Training TL due to additional factors other than injury has the potential to increase the risk of injury due to improper warm-up and underexposure.

Results from the current study report the highest percentage of TL were seen due to injury, which may be the reason as to why studies publish injury TL alone. Injuries, especially when classified as severe or season ending, keep an athlete out of competition for extended periods of time, increasing injury TL. No studies to our knowledge report additional reasons for TL in our categories. It is important to note additional TL factors may influence IR.

### Injury Rates.

Few studies have examined IR in collegiate soccer. Of those, IR were reported per 1000 athlete exposures (AE), and include the NCAA. As demonstrated from this study, this method can have variation in rates when comparing IRs per 1000 EHs. Injury rates were lower than NCAA Division I Men's soccer for practice with 2.6 vs. 4.6 injuries per 1000 AE in practice, and higher for matches at 40.9 vs. 21.9 injuries per 1000 AE. This may be due to the fact that the NCAA did not calculate IR during the offseason where we additionally saw high match IRs (50.0 per 1000 AEs), 52.8% injuries occurred during a match, and also due to the limited number of athletes with this study. It is difficult to decrease match IR where an athlete is expected to perform at their highest level of competition against an opponent. Practice injuries, on the other hand, can be minimized through proven methods such as injury prevention programs,<sup>76</sup> proper warm-up,<sup>48</sup> and appropriate training programs.<sup>131</sup> Due to a low number of practice

injuries, it may be seen that this team was able to limit the number of training injuries based on their training program during the regular season.

No studies have calculated IR during the offseason. Practice IR were higher during the offseason, than any other season of training. This is essential for coaches to know when creating a training program, and athletic trainers when treating and managing injuries. Creating a proper training program is an important aspect of coaching, which can be challenging when managing an entire team when athletes arrive on varying levels of performance, cardiovascular fitness, and technical skill.

Differences were seen with this team when comparing IR per 1000 AE and EH. When comparing offseason IRs in formal practice we found that IR per 1000 AE were consistently higher than that per 1000 EH rates. Table 2.25 depicts 4.6 injuries per 1000 AE vs. 2.9 injuries per 1000 EH. Table 2.24 show in-season match rates of 40.5 injuries per 1000 AE vs. 33.2 injuries per 1000 EH, 3.2 injuries per 1000 AE vs. 4.0 injuries per 1000 EH during S&C. Sensitivity and consistency of IRs are greater when calculating for EHs. Per the NCAAs definition of an AE, a match can have 11+ AE, while only a maximum of 11 players per team are on the field at once. A regular match lasts 90 minutes, with a total of 16.5 possible team EHs. If there was 1 injury, and 20 AE, there would be an AE rate of 50 injuries per 1000 AE, or if only 11 athletes were on the field, an AE rate of 90.9 injuries per 1000 AE. If accounting for EH, this same example would produce a rate of 60.6 injuries per 1000 EH, regardless of AE.

Injury rates are more commonly examined per 1000 EH at the professional soccer level and with individual teams as this study did. A collegiate team cannot accurately be compared to that of a professional team, but for the purpose of comparing

EH IRs, this team fell within normal ranges of previously reported rates. Injury rates by EH with this team during practice were 2.1 injuries per 1000 EHs, which fell within reported IRs that vary from 2.1-11.8 injuries per 1000 EH, and 35.6 injuries per 1000 match EH which falls in line with previously reported rates ranging from 20.6-53.0 injuries per 1000 EH. Difficulties can be seen when calculating EHs in large studies such as that performed by the NCAA, but with wearable technology now commonly being used at all professional, and recently introduced into the collegiate and youth levels, teams can more feasibly calculate an individual athlete's EH.

It is assumed the NCAA calculated S&C training as an AE per their definition of an AE,<sup>69</sup> but they did not separate out training types when reporting rates, which can have varying effects. Though one of the purposes of S&C training is to prevent injuries, injuries commonly occur during this form of training as demonstrated during the offseason of this study where there was an IR of 4.0 injuries per 1000 EHs. There were no injuries during preseason, in-season or postseason during S&C, which could be a reflection of the limited EHs (entire Fall = 93.55 EH vs. Spring 746.25 EHs), and the intensity of training as directed by the S&C coach during the offseason. If this team did not have S&C EHs during the postseason, we may have seen greater IR during formal training. Exposure in S&C could have reduced the IR during formal training and matches; without the strength and power component from S&C sessions, athletes may not be as well prepared on the field.

Injury rates during summer training could not be accurately reported due to the uniqueness of summer training and possible underreporting. Strength and conditioning sessions held during the summer were provided as a service to the athletes and not

mandated, therefore, if an athlete had a physical complaint due to training, they may not have arrived to practice for several days due to the injury, which could not always be traced as the training sessions were not required. Additionally, there was potential for underreporting of injuries to the ATC, thus not all physical complaints were documented as injuries in the database where data for this study was extracted. Furthermore, as training was optional, there may have been low pressure to return to their proper fitness level as quickly as they did while in-season, and athletes did not always seek additional services. When training for the purpose of S&C, modifications can be made, even in the case of a physical complaint, medical attention, and possible injury. Furthermore, training adjustments were made and provided on a two week training modification plan to athletes who had not attended prior training sessions, or inconsistently, with the S&C coach. Individual training performed outside of the university (i.e. when the athletes trained at their homes or elsewhere), were not calculated, and could not be counted towards EHs regardless if their training plan followed the recommendations from the S&C coach. To account for EHs outside of scheduled training, future research should utilize further data collection methods with additional documentation. An example of this would be a program where an athlete reports what they did for training, training duration, and if they experienced any physical complaints due to that day's training.

#### Injury Prediction.

We unfortunately had 4 players who comprised the 41% of injuries that occurred in field players. Therefore, we were unable to determine relationships between injured versus non-injured players. Our correlations would have been spurious correlations at best. We will continue to collect more injury data to add to our model. In turn, we

examined 4 individuals in search of descriptors as to probable causes of injuries seen with these athletes.

### Case Studies.

*Exposure Minutes.* Exposure minutes (EM) were consistently the highest during preseason and offseason for all 4 individuals, and lowest during summer training. The average conditioning session for the team during the summer was 35 minutes, while formal training for the rest of year was an average of 96 minutes. Exposure minutes varied for each individual based off of training modifications made, injuries and match minutes. Case 2 had the highest training and match EHs at 269.85 for combined training, and 44.55 hrs played in a match. On the contrary, C3 had the least amount of both training EHs at 196.9 hrs and 8.9 match hrs. There were 0 EMs during days 53-62 for the entire team during Spring break for all cases, and from days 95-111 following the end of the spring semester (end of offseason) and prior to the start of summer training. As seen with C1, this athlete was underexposed during summer, and required more modifications during summer, preseason, and in-season. In C3 and C4, limited EMs were seen during the postseason due to injuries. As training EMs increased, more modifications were provided to 3 of these 4 athletes. It was found during the offseason trainings were longer than the in-season for 3 of the 4 athletes, where 2 of the athletes ended their season due to injuries and 1 of the athletes was provided with more modifications and was ultimately injured. Time is the underlying factor when creating a training program, which can have effects on PL and HR measures.

*Player Load™.* When observing PL for the entire team, we can see variations in load for each individual. During the later portion of the season, we can see in C1 that as

the PL increased, more injuries and physical complaints were reported. It is important to note the injuries reported during the later portion of the year for this individual were musculoskeletal injuries, which can be affected by training loads. In C1, C3, and C4, injuries and physical complaints occurred even during the lowest PLs, which were seen during summer training. Global positioning units to collect PL were only worn during conditioning sessions as they would during formal practice during all the other seasons. Summer training had a high emphasis on strength and power, and only one training was held per individual each day, whereas the offseason generally had two trainings a day; formal practice in the morning and S&C training during the evening. In C3 we can see physical complaints occurred more during the time where his PL was within 1SD, and even 2SD below the mean due to the type of injury he sustained. This injury was chronic, with re-current complaints until the beginning of in-season where the athlete ended the season due to his injury, which required an operative route. This athlete never fully returned to play following this injury, but experienced loads during training as tolerated and recommended by the ATC, as displayed in the graph.

*Training Impulse (TRIMP).* When analyzing TRIMP in all cases, it is displayed that scores were highest and exceeded 2 SD during preseason, which could be contributed to the 3 two-a-day sessions. Case 2 presents with the highest TRIMP during preseason, in-season and postseason, with one exception during offseason. This individual was able to withstand high scores without getting injured; this athlete exceeded 1SD on 29 instances, and 2 SD on 14 occasions. Case 3 demonstrates in the TRIMP scores this athletes inability to fully return to play based off the scores below the mean, with only 2 of the data points exceeding the mean. When examining each training

session for C4, the second highest TRIMP score was seen during the final match this athlete performed during the year, and when examining per training day, this was the 4<sup>th</sup> highest TRIMP score. This is important to note for this specific case as his injury was a non-contact internal injury.

*Heart Rate Reserve (HRres 85-100%).* Training in these high intensity training zone percentages varied for each of the 4 cases. In C1 the athletes mean was the lowest of the 4 at 4.4% of time in this zone, and exceeded 2SD in 7 instances. The highest percentage of time spent in a high heart rate zone for C1 was seen on the first days of training during the off and preseason. On the contrary, C4s mean HRres was the highest at 18.4% of time in this zone, and exceeded 1SD on 18 instances. When examining HRres for C4, it is important to note that when examining the percentage of time spent during this high intensity, his overall score for the final match he played nearly exceeded 3 SDs of his mean, and was the highest percentage of time spent in zone 85-100% when examining the entire year. This may warrant future attention when examining internal injuries and important to take note of when an athlete reports internal physical complaints.

Data from EMs, PL, TRIMP and HRres in 85-100% do not show consistencies in all 4 cases. When examining injuries, a multitude of factors should be taken into consideration; there is not one method of evaluating training and therefore injury prediction, but a variety of factors that include EMs, PL and HR.

## **2.51 Limitations**

The current study had limitations with varying degrees. It was assumed that all participants reported all prior injuries during their pre participation examination (PPE)

when entering the university. Limitations of collecting past medical data is that the past injuries examined were documented injuries; though not all injuries may have been reported and documented in their original PPE. Limitations were seen with IR during the summer training; injuries may have been underreported to the ATC and therefore not documented as an injury in the database where injury data was collected.

Additionally, the devices used in this study were of older generations and did not always collect the necessary data from the training session, creating missing data points. Future studies should utilize latest technology to ensure proper data collection. Furthermore, not all field players wore their devices during matches so we could not get a true representation of their PL for those sessions. Increasing the level of player buy-in is warranted for future studies as seen with wearing athlete monitoring devices.

With the aims of creating an injury prediction model, limitations were seen with the low number of injuries to be included for analysis. Further investigations should be made with a larger sample size with teams who experience high non-contact musculoskeletal injuries. The current study demonstrates factors associated with injuries in 4 individuals, and provides an example of measures to be included for analysis with the aims of injury prediction.

## **2.52 Applicability/Clinical Use**

Time loss can be significant in that it may not always be due to an injury, but also can cause the injury due to underexposure and undertraining. Findings from this study suggest that calculating IRs per 1000 EHs may be more accurate to calculating per 1000 AE. Injury rates are important to calculate not only during preseason, in-season, and postseason, but during the offseason as demonstrated by the high IRs in the current



study. It is important to record AE and training EH when creating training schedules and individualized training programs. Various forms of athlete monitoring and devices can aid in calculating an athletes training EHs. In addition to knowing when the athletes train, it is imperative to know what the athletes do during training, and the physiological responses to their training regimen. Both undertraining and overtraining can result in injury, and varies for each individual based on their fitness level, position, and what is expected of them during training. Quantifying both internal and external loads can aid in creating training programs tailored to individual training specifications based on their adaptations and/or positional requirements. In the case of EMs, we can see in 3 of the 4 cases that training modifications were made during the preseason when EM were highest as seen from double-sessions. When training for quantity, data from these athletes suggest they were unable to maintain peak performance and provide the same amount of quality work as demonstrated in shorter training days, and when there were only 1 session in a day. As demonstrated in C4, training in a high intensity HRres from 85-100% that nearly reached +3SDs from the athletes mean when reporting internal physical complaints may warrant future attention. Heart rate load measurements such as TRIMP can be a good indicator of fitness level and be applied when creating a return to play protocol for an athlete post-injury. Training can be based off a pre-determined combination of HR and PL data based off the individuals pre-injury mean scores, with increasing PL and aims to decrease TRIMP as HR during the first few days of training can often present scores above their mean.

### **2.53 Future Directions**

The outcomes of the present study indicate that more research is needed and should focus on TL, IR calculation consensus and injury prediction. When analyzing TL data, reasons for TL in sport will vary with playing level. At the collegiate level, reasons include: injury, illness, academics, coach initiated modifications, and other, whereas at the professional level TL may only be seen with injury. Future studies should examine reasons for TL at all levels, and incorporate illness in addition to IRs as predictors of TL. In regards to IR and AEs, future studies should examine EH as well as exposure location (i.e. formal practice vs. S&C, and match) in order to further examine IRs in all areas of training. Finally, when creating an injury prediction model, a vast number of non-contact musculoskeletal injuries should be examined in large sample sizes utilizing wearable devices and perceptual measures. Future studies should examine not only chronic load, but acute training load on a weekly basis. Additionally, the magnitude of percent change can be examined with training loads in conjunction with non-contact injuries to determine if there is a correlation to training loads and IRs.

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