The Ability of Internal and External Workload to Predict Soft Tissue Injury of the Lower Limbs in College Female Soccer Players

by

Ai Ishida

A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
the Master of Science

Approved April 2018 by the
Gradate Supervisory Committee:

Pamela Swan, Chair
Joshua Beaumont
Jesse Vezina

ARIZONA STATE UNIVERSITY

May 2018

ABSTRACT

Background***:*** Understanding an athlete's workload is one way to determine the likelihood of receiving a sports injury. Workload variables are categorized as either internal load (IL) such as heart rate, or external load (EL) which include speed, distance or volume. Objective: This study investigated the correlation between IL and EL measured by micro-technology in female college soccer players. In addition, the utility of IL and EL to predict risk of soft tissue injury on lower limbs was examined. Method: 23 NCAA Division One women soccer players 19.2 ± 1.2 years old, 168.2 ± 7.3 cm, and 141.0 ± 17.9 kg were recruited. Only field players with no prior lower limb injuries were included. IL measurements collected were ratings of perceived exertion (S-RPE), average heart rate (Avg-HR), training impulse (TRIMP i.e., HR x time) and estimated maximum heart rate (Max HR). Total distance (TD), average speed (Avg-Spd), high speed running distance (HSR), estimated maximum speed (Max speed) and intensity volume index (VI index) were identified as EL. The workload data were categorized as being either acute or chronic. Acute was defined as the measured average workload the seven days immediately prior to the injury, while chronic workload meant the average workload 21 days before the athletes were hurt. Spearman correlation was used to examine the relationships between IL and EL and one-way ANOVA and Kruskal Wallis tests were conducted to investigate the mean differences between injury groups. Results: There were significant positive correlations between S-RPE and TD ($r = .82, p < .001$), TRIMP and TD ($r = .75, p < .001$), Avg-HR and Avg-Spd ($r = .80, p < .001$), and H-HR zone and HSR ($r = .60, p < .001$). The results indicated that the acute Avg-HR, the A/C ratio of Avg-Spd and VI index were significantly ($p = .001$) higher in the injured compared to the non-injured group. Conclusion: The study indicated that internal and external load were significantly correlated in this group of female soccer players. Also, acute Avg-HR and A/C of speed and volume index may predict the risk of soft-tissue injury in female athletes.

ACKNOWLEDGMENTS

I would like to express my very sincere appreciation to my committee chair, Dr. Pamela Swan for constructive advice, useful critiques, and engagement throughout the creation of this master's thesis. She was willing to take my committee chair and I could not have finished this thesis without her. Also, I am very grateful to my committee member Joshua Beaumont for the engagement in a part of data collection and kindly took care of the process of this master's thesis. His wisdom gave me different perspectives to push my research to higher levels. I am honored to have worked with him. I also appreciate to my committee member Jesse Vezina for his great assistance on my thesis. He advised me to improve from the viewpoint of strength and conditioning. I appreciated to Blake Whitney that he gently instructed how to collect data by a heart rate monitor and a global positioning system. Furthermore, I am very thankful to all coaches working for the soccer team at Arizona State University. They helped with the injury collection part used by the injury history report. Finally, I could not express my gratitude to my family over these last two years. They supported me financially and mentally when I was enduring tough times. I would like to show my gratitude again for all persons involved in my master's thesis, thank you so much for everything you did.

TABLE OF CONTENTS

Page

APPENDIX

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

Chapter 1

INTRODUCTION

Advances in new technology are helping to reduce the risk of injury in sports through workload monitoring. In particular, wearable micro-technology devices such as heart rate (HR) monitors and global positioning system (GPS) units that can quantify workload during practice and in game play are emerging (Bourdon et al., 2017; Carey et al., 2016; Gabbett., 2016; Gabbett & Ullah., 2016; Hulin, Gabbettm Lawson, Caputi & Sampson. 2016; Malone et al., 2017). For example, Malone et al., (2016 & 2017) recently reported that higher training loads, as measured with GPS, were significantly correlated with injuries in sport athletes. As a result, sports medicine recognizes the vital role that HR monitoring and GPS has in injury prevention.

It is well known that there is a dose response relationship in regard to training and athletic performance. Athletes generally obtain better performance if they train at a high frequency and high intensity (Foster et al., 1977; Mujika et al., 1995). However, risk of injury also increases as volume and intensity increase. Arason et al, (2004) reported that overall better team performance was positively correlated to a fewer number of injury days. In fact, Brooks et al., (2005) showed that injury from training can be major problem in team sports as rugby union players in English Premiership Club missed on average 12 days for each training injury. Thus, a sports medical team is challenged to maintain the best balance between performance enhancement and injury risk of their players.

Workload is categorized into two parts: internal load (IL) and external load (EL) (Bourdon et al., 2017; Vanrenterghem, Nedergaard, Robinson & Drust, 2017). IL indicators are considered biological or “internal”. Values of average heart rate

(Ave-HR), training impulse (TRIMP), which is the product of average HR and session duration (min), blood lactate, oxygen uptake (VO_2), and ratings perceived of exertion (RPE) are all IL indicators. On the other hand, EL are considered the "external" work patterns that the player performs. Variables such as total distance (TD), high speed running distance (HSR), and acceleration are typical EL indicators.

HR, RPE and TRIMP, which provides an estimate of training volume during a session, are the typical IL variables used to monitor injury risk. Owen et al., (2015) discovered that the injured male soccer players spent significantly more time at a high intensity HR zones (85 to 89% of HR max) and a very high HR intensity zones (over 90% of HR max) than those not injured. Also, Malone et al., (2017) showed that the groups accumulating higher session-RPEs (s-RPE) in preseason had higher risk of injury than the reference group.

Wearable GPS technology provide the sports medical team critical EL data help develop an injury prevention strategy. Gabbett & Ullah (2012) examined the effect of the running workload on soft-tissue injury in National Rugby League players. Their data indicated that the group that ran the greatest distances at a speed above 7m/s were at significantly increased the risk of injury than those who trained at lower speeds or less distance (RR= 2.7, $p<0.05$). They also revealed that the group running more at mild and very-mild intensity had a lower risk ratio (RR=0.4, $p<0.05$ and RR=0.5, $p<0.05$). In addition, Ehrmann et al., (2016) investigated the association between running profile and non-contact soft tissue injury risk in Australian elite soccer players. They found that the 1-week and 4-week average running speed of the injured group was higher ($p=0.008$ and $p=0.008$) than the season average speed of all non-injured players. Thus, those in the injured group seemed to have a different and higher EL running profile than those who were not injured.

In recent years, Hulin et al., (2016) advocated the theory of acute to chronic workload ratio (AC ratio), which is based on Banister's original fitness-fatigue model (Banister, 1991). AC ratio helps to understand how prepared an athlete may be in regard to their fitness and their level of fatigue (Bourdon et al., 2017; Gabbett, 2016). The model is valuable for trainers and practitioners to help them determine the "sweet spot" between the highest workload and lowest likelihood of injury. Acute training volume correspond to 2 to 7 days while chronic workload ranges from 2 to 5 weeks (Caley et al., 2016). The AC ratio is commonly calculated with both EL and IL variables (i., e., running variables, heart rate variables or RPE) (Carey et al., 2016; Hulin et al., 2016; Malone et al., 2017; Malone et al., 2017). Blanch et al., (2015) summarized the studies relating to AC ratio and likelihood of injury, and concluded that the AC ratio with the lowest risk ranged from 0.8 to 1.3.

In soccer, lower limbs are the prime sites to sustain injury. Mufty et al., (2015) suggested that ankle injury, distortion of a knee and contusion of a knee were common injuries in soccer players regardless of gender. Soccer players who play with more intensity tend to suffer more injuries. Ehrmann et al., (2016) indicated that Australian elite soccer players had significantly higher the average speed than the season average ($p = 0.008$). Owen et al., (2015) showed that the amount of time spent at more than 90% HRmax was significantly correlated to the injury incidence in professional soccer athletes ($r = 0.48$, $p = 0.02$). Also, Brooks et al., (2008) indicated that professional rugby players who trained in the highest training volume group (> 9 .1 hours) in the competitive season sustained significantly more severe injuries than those who trained in the lower group (6.3 to 7.4 hours).

Although previous studies have described IL and EL activities, previous studies have not fully examined the relationships between IL and EL (for example;

volume, intensity and volume at high intensity). Also, although past research considered IL or EL as one of risk factors of injury (Ehrmann et al., 2016; Gabbett & Ullah., 2012; Malone et al., 2017; Owen et al., 2015), there is no consensus as to what variables may be the most predictive of injury risk. Finally, the previous reports on training workload and injury risk have only described the findings for male athletes. It is not known if these same variables are applicable in women athletes. Thus, it is critical to describe the relationship of workload variables and injury risk in female athletes to help prevent injury and improve performance in this population.

The first purpose of the study was to investigate the correlation between internal and external load in female college soccer players. The second purpose was to identify the mean differences in internal or external load between non-injured and injured groups to predict risk of soft tissue injury on lower limbs in female college soccer players. Specially, the questions of the study are following:

1. What is the correlation between internal and external load for volume: (i.e. s-RPE and total distance; TRIMP and total distance); intensity: (i.e. average heart rate and average speed); and volume at a high intensity: (i.e. time at a high heart rate zone and high speed running distance) in women college soccer players?

2. What the differences in internal load (i.e. session ratings of perceived exertion, training impulse, average heart rate, and time spent at a high heart rate zone) or external load (i.e. total distance, average speed, and high speed running distance) between injured (i.e., soft tissue injury on lower limbs) or non-injured college female soccer players?

Hypothesis:

1. There will be no significant correlation between internal and external load in volume factors (i.e. session ratings of perceived exertion and total distance,

and training impulse and total distance), in intensity factors (i.e. average heart rate and average speed) or in volume at a high intensity: (i.e. time at a high heart rate zone and distance at a high speed) in women college soccer players.

2. There will be no significant differences between injured and non-injured players in internal load variables (i.e. session ratings of perceived exertion, training impulse, average heart rate, and time spent at a higher heart rate zone) or external load variables (total distance, average speed, high speed running distance, and running speed) in women college soccer players..

Chapter 2

REVIEW OF LITERATURE

Introduction

Micro-technology monitoring is vital to team sport's injury prevention. The representative devices are a heart rate (HR) monitor and a global positioning system (GPS) unit. The technologies contribute to visualize workload such as intensity and volume in a training and a game. Jones et al., (2015) analyzed the running patterns and the accelerated activities in European professional rugby players. The result showed that different playing positions required specific movement characteristics during a game. Sport science teams can examine athlete's movements using HR monitors and GPS Units, which can help prevent injuries and enhance sport performance.

Generally, athletes' performance is more successful if they can train at both higher volume and intensity (Foster et al., 1977; Mujika et al., 1995). However, a likelihood of injury is higher when workload stresses exceeds a threshold of this work capacity. Thus, considering workload, sports medical teams can strategize prevention programs.

Workload is classified into two parts: internal load (IL) and external load (EL). IL expresses biological reaction in a body like heart HR, Borg's rating of preserved exertion (RPE), blood lactate (La) and so on. EL is work patterns that a player performs in a given activity.

In 2016, a new idea using IL and EL came out to prevent injury: acute to chronic workload ratio (AC ratio) (Hulin et al., 2016). The concept was originated from Banister's fitness-fatigue model. AC ratio can describe the relationship between short term (acute) and moderate-term (chronic) training loads (Gabbett, 2016). AC ratio should make practitioners evaluate the appropriate spot between workload and lower limb injury occurrence. Acute workload is a sum of 2 to 7-day workload while chronic workload is defined as a mean of 2 to 5-week workload. The past studies used running distance, session-RPE (s-RPE), and HR variables to calculate AC ratio. (Carey et al., 2016; Hulin, Gabbett, Lawson, Caputi & Sampson. 2016; Malone et al., 2017)

Lower limb injury is the biggest issue in soccer players. Sprained ankles, bruised knee and knee ligament/join problem are common in soccer regardless of gender (Mufty et al., 2015). Also, Stubbe et al., (2015) showed that the 80% of the injured site was the lower limb in Dutch male professional soccer players. Wong and Hong (2005) reported that soccer players sustained more injury at ankle, knee, upper leg and foot.

Internal Load (IL) Monitoring

Ratings of Perceived Exertion. (RPE). RPE is a scientific method to specify work intensity inside the body. The advantages of RPE are convenience and cost-efficiency. Also, RPE can be applied for all training modalities to quantify workload. Meanwhile, the disadvantage is subjective evaluation. RPE is a valuable tool for an athlete who cannot put on a HR monitor during a game or a practice. The modified Borg CR-10 Scale is commonly used to define session intensity (Impellizzeri et al., 2004; Gabbett, 2016; Malone et al., 2017).

Session-RPE (S-RPE) by Foster et al., (1995) is the most convenient and the cheapest method to quantify internal training volume (Arbitrary unit: AU), which is the product of PRE scare and time during a session (min). In soccer, Impellizzeri et al., (2004) quantified workload in training using S-RPE. Also, Scott et al., (2013) found that s-RPE was strongly correlated to running distance in Australian professional soccer players.

Gabbett (2010) published the first article predicting non-contact soft tissue injury using s-PRE. Although it did not reach a clear conclusion, the result suggested that injury risk would increase exponentially over a given point. Also, Rogalski, Dawsona, Heasmanb, and Gabbett (2013) examined the relationship between injury risk and S-PRE in Australian Football players during 2010. They reported that the groups with high 1-week accumulation (>1750) had significantly higher odds ratio than the reference group (<1250 AU) (OR = 2.44, $p = 0.007$). Furthermore, Malone et al., (2017) reported that injury risk was positively related to workload accumulation and change between weeks in European professional soccer players.

The validity and reliability of RPE to identify workload should be considered because RPE score is determined by subjective evaluation. However, past studies revealed correlation between RPE and HR. In the pilot study by Foster et al., (1995), S-PRE was moderately corresponded to average percentage HR reserve during 30 min steady running ($r = 0.65$). Another research by Alexiou and Coutts (2008) reported that S-RPE was strongly correlated to HR-based training load for several trainings in elite female soccer players ($p<0.001$). Edwards training load was significantly correlated to the S-RPE of conditioning ($r = 0.79$, $p < .001$), speed training ($r = 0.79$, $p<.001$), and technical training ($r = 0.82$, $p <.001$). Also, the correlation between S-RPE and total distance in elite wheel chair rugby players was moderate ($r = .59$)

Heart Rate (HR). A HR implies internal training intensity in team sports setting. HR intensity zone is typically categorized into 5 zones: 50 to 60%, 60 to 70%, 80 to 90%, and above 90% of HR maximum (HR max). Times on each zones decides how hard efforts athletes make. The advantage of HR is to monitor physiological status inside body at a certain intensity. However, the biggest limitation is that the zones are based on HR max (Halson., 2014). In clinical field, age-based predicted HR max are commonly utilized as an alternative thanks to the convenience. However, Nokolaidis (2014) reported that the score of the age-based HR max were significantly different from that of the measured HR max in soccer players.

Presently, HR plays a vital role on injury prevention. Owen et al., (2015) examined the effect of times at high HR intensity on injury occurrence in elite soccer players. The outcome showed that the total number of injuries was significantly correlated to time at the high training intensity (85 to 89% HR max: r=0.57, p=0.005; above 90% HR max: r=0.57, p=0.005). Also, the time spent above 90% HR in the injured group was significantly higher than the non-injured group (p=0.04).

HR monitoring has been introduced in soccer since 1960s to identify physiological load during a practice and a game. According to the review article by Alexander et al., (2012), the average heart was between 165 and 175 beats/min regardless of age and gender.

Training Impulse (TRIMP). Banister Training impulse (TRIMP) was developed in 1991 to quantify training load. Banister TRIMPH is calculated as follows: Banister TRIMP (arbitrary unit: AU) = Session duration (minutes) x (HRexercise - HRrest) / (HRmax – HRrest) duration (minute) x $64e^{1.92x}$. Two years after Banister TRIMP was proposed, Edwards (1993) suggested Edward summated-heart-rate-zones (SHRZ) model which decides training load based on predefined five heart rate zones.   TRIMP can consider the effect of both intensity and volume by through HR monitor. However, TRIMP is not be validated when HR max is not measured correctly. Paulson, Mason, Rhodes and Goosey-Tolfrey (2015) reported that total distance and TRIMP score (both Banister and Edward SHRZ) were strongly correlated (r = 0.81 and 0.84) in elite wheel chair rugby players. Thus, TRIMP would have a great potential to monitor fatigues originated from training sessions and games.

External Load (EL) Monitoring

Global Positioning System (GPS). The American Department of Defense started the navigation system GPS for military purposes, and then the system has been introduced in sports since 1997 (Cummins et al., 2013). GPS is composed of 27 operational satellites in orbit around the clock with each satellite having an atomic clock. The stations continually send information and signals to the receivers. Distance from satellites to a receiver is calculated using the speed of light and signal travel time. At least 4 satellites are required to calculate exact information (Larsson., 2003). The error sources of implementing GPS are the atmosphere and local obstructions before the signals arrive to the receiver (Larsson., 2003).

Application of GPS for injury prevention develops in team sport settings. The device allows a sports science team to analyze movement patterns during a practice and a game. The micro-technology quantifies total distance covered (TD) (m), average speed (m/min), high speed running distance (HSD), maximum velocity (m/s), acceleration (m/s/s), deceleration (m/s/s), work rate pattern, body load (G) and so on. Past studies think of TD and HSD as training volume and average speed as training intensity. Malone et al., (2015) quantified workload during entire season in English professional soccer players.

Sports scientists generally use TD, average speed and HSD to predict injury risk. Gabbett and Utah (2012) published the first study about the effect of a running distance on soft-tissue injury. Ehrmann et al., (2016) revealed that the average speed in the injured group was higher than the average in the entire season. In addition, Malone et al., (2017) examined the effect of HSD on the injury incidence in elite soccer players. The data showed that the largest group with absolute weekly change of HSD had higher injury risk than the reference group. Unfortunately, researchers did not reach the consensus about what kinds of EL will increase injury risk.

The biggest concerns of GPS technology are its validity and reliability. If these values are not within optimal ranges, researchers cannot compare with each session and give feedback to coaches because of the inaccuracy. Commercially, a company sells 1Hz, 5Hz, 10Hz and 15Hz of GPS.

There are two main determinants to affect validity and reliability. One of the determinants is a sampling rate of a GPS unit. One review article by M. Scott, T. Scott and Kelly (2015) showed that the 10Hz and 15Hz GPS unit were more validated and accurate than the 1Hz and 5Hz units. The validity of 10Hz GPS unit investigating short sprint and TD was good validity at 4 sports-specific protocols (Vickery et al., 2014). Also, Rampinini et al., (2015) revealed that the coefficient of variance (CV) of 1 10Hz GPS looking to TD and HSD were good (1.9% and 4.7% each) in a field based high-intensity running protocol.

The other main factor to affect GPS validity and reliability is a measurement item. Generally, a GPS unit can accurately quantify TD even if the sampling rates is lower (Scott et al., 2015). However, as speed of task increases, the validity and reliability of 1Hz, and 5Hz were lower. Vickery et al., (2014) compared with the accuracy of 5, 10, and 15Hz GPS unit using a field based sports protocol. The result showed that there were no significant mean differences of total distance, estimated speed and average speed between all GPS and VCON ($p>0.05$). Scotts et al., (2015) concluded that only 10Hz GPS overcame the limitations during high-intensity short distance running. They also reported that the validity of a change of direction (COD), work rate patterns and body load (BL) were poor.

Regarding reliability, intra-unit reliability of a GPS is higher than inter-unit reliability, so athletes should put on the same unit as much as possible (Scott et al., 2015). To summarize, collecting distance and speed by 10Hz GPS can make research valid and reliable.

To summarize, a 10Hz and 15Hz GPS unit have high validity and reliability to investigate TD and HSD. The validity and reliability of a COD, work rate patterns, and BL are poor.

Relationship between Internal Load and External Load

Manzi, Bovenzi, Impellizzeri, Carminati and Castagna (2013) researched the relationship between internal load and aerobic fitness in professional soccer players. The result showed that the weekly change of iTRIMP was significantly related to VO2max ($r=0.64$, $p=0.004$). In addition, Malone, Doran, Akubat and Collins (2016) examined the association between aerobic fitness (maximum consumption of oxygen(VO2max), velocity at lactate threshold (vLT), and velocity at onset of blood lactate accumulation(vOBLA)) and external loads. There was significantly moderate correlation between vLT and HSR ($r=0.485$, $p=0.012$). However, VO2max was not significantly associated with TD. ($r=-0.158$). Scanlan, Wen, Tucker and Dalbo (2014) examined the relationship between accelerometer-derived EL and Banister TRIMP or Edwards SHRZ model. The result showed that Edward SHRZ model was strongly correlated with the EL ($r=0.61$, $p\leq0.001$). Furthermore, Manzi, Iellamo, Impellizzeri, D’O and Castagna (2009) reported that iTRIMP was significantly associated with 5000-m ($r=-0.77$, $p=0.02$) and 1000-m ($r=-0.82$, $p=0.001$) running performance in distance runners.

Acute Chronic Workload Ratio (AC ratio). Hulin et al., (2015) theorized AC RATIO based on Banister’s fitness-fatigue model. The model mentioned the association among preparedness, fatigue and fitness. Acute workload is calculated as roiling to 2 to 7-day workload while chronic workload points to 4 to 6-week total workload (Bourdon et al., 2017). In a sport analysis field, s-RPE, and TD are generally used to quantify AC RATIO (Bourdon et al., 2017; Carey et al., 2016; Gabbett., 2016; Hulin et al., 2015; Malone at al., 2017).

Hulin et al., (2015) published the first article to reveal the relationship between injury risk and AC RATIO of TD. Also, Malone et al, (2017) examined the relationship between injury risk and AC RATIO of s-PRE in competitive European soccer players. The result suggested that the in-season injury risk of AC RATIO ranging from 1.00 to 1.25 was lower than the s (OR=0.28, p=0.001). Although AC RATIO helps sports scientist identify likelihood of injury, the number of articles published are not quite a lot.

Injury in Soccer

Injury Epidemiology. The biggest site injured in soccer players is a lower limb regardless of gender, nationality, and age. Mufty et al., (2015) found that ankle problems, and distortion and contusions of the knee were commonly sustained in Belgian soccer players. Also, 82.9% of the injured sites in Dutch professional male soccer players was a lower limb (Stubbe et al., 2015).

Speaking of injury type, soft-tissue injury is the most common problem in soccer. In particular, sprains and contusions account for the higher percentage. In both female and male players, a sprain was the most frequent injury, followed by a contusion (Mufty et al., 2015). The most common injury type in elite Ducth soccer players was muscle and tendon problem. The second most frequent diagnoses were joint and ligament injuries (Stubbe et al., 2015). Volpi and Tailon (2012) examined the risk factors of injury in professional soccer players.

Injury Risk Factors. Injury risk are decided by variety of factors like skill, environment, physical capacity, anatomy, biomechanics, mental condition and so on (Volpi & Taioli., 2012). This research focus on mode of play, gender, and training variables.

Mode of play. First, mode of play is one of the risk factors of injury. In soccer, more injuries resulted from a game than a training session. Stubbe et al., (2015) showed that the injury incidence in a training session and in a game were 2.8 times and 32.8 each per 1000 player hours Dutch professional soccer players happened during a game. Also, the data from 13 articles summarized by Wong and Hong (2004) showed that injury rate in a game was higher than a training session except for one articles. However, Malone et al., (2016) stated that training injuries incidence (6.9 times per 1000 hours) in Australian professional soccer players was than the match incidence (4.9 times per 1000 hours).

Gender. Next, sex difference has a great influence on anatomical characteristics in lower limb injuries. In particular, a distribution of a knee injury varies depending on gender. Research by Ristolainen, Heinonen, Waller, Kujala and Kettunen (2009) reported the effect of gender on the injury risk in college soccer players was small, but the proportion of an acute ligament injury in the female was higher than in the male (71% vs 42%, p=0.01). In addition, NCAA injury survey showed that the odds ratio of the knee injury in female soccer players was significantly higher than in the male (OR=1.44, p<0.001) (Fulstone, Chandran, Barron & DiPietro, 2016). The meta-analysis by Walden ́et al., (2011) showed that the female soccer players sustained ACL ruptures 2-3 times higher than the male.

Volume. Training volume is one of factors that affects injury incidence. Although training volume increases in professional rugby union players, the number of injuries originated from the overuse would increase. During the competitive season, those who had high training volume (>9 .1 hours) sustained severer injuries than the group who experienced 6.3 to 7.4 hours (Brooks et al., 2008).

Intensity. The studies examining the relationship between injury risk and training intensity are not enough. Malone et al., (2017) reported that injury risk in the group who accumulated the most sprint distance was significantly higher than the reference group (OR=3.44, p=0.004). Thus, accumulation of workload at high intensity may lead to increasing injury risk.

Soccer. Soccer is one of the popular sports in the world. In FIFA regulation, each team is composed of eleven players and both teams play the game in a rectangular field. The movement patterns are mainly composed of kicking, heading, dribbling, running, tackling, jumping, acceleration, deceleration, and a change of direction.

Elite soccer players requite highly physiological characteristics. In 2014 Brazil World Cup, the average TD was 10.07±0.96 km. The mean percentage to run at the higher velocity (19.9 – 25.2) was 8.83±2.11% (Chmura et al., 2017). Salvo et al., (2009) reported that shorter sprints (0 - 10 m) occurred more frequently than longer sprints (above 10.1m) in English premier leaguers.

Female soccer players generally do not need as much physical capacities as the males. In the elite Danish female soccer players, the average TD was 10.3 km, and the time running at the high-intensity was 4.8% of the total time (Krustrup, Mohr, Ellingsgaard, & Bangsbo., 2005). Also, Hewitt, Norton and Lyons (2014) reported that the average TD in Australian national female soccer players was 9.6±0.17 km, and the distance running at the high intensity was 2.4 ±0.13km.

Chapter 3

METHODS

Participants

Twenty-three NCAA division 1 women soccer players were recruited. The season consists of 14-week competitive season. To be eligible for the study players must be field players and had not sustained an injury before the season started.

Procedures

This study was a retrospective data analysis so a written informed consent was waived. All experimental procedures were approved by and met the guidelines established by the Human Subjects Review Committee at Arizona State University. This is non-invasive observational study of athletes during their normal practice and game play.

Data collection started in August and were completed by the beginning of the December. After data collection, result and discussion parts were written by February. And then, the thesis defense was conducted on April 2018. The study should be published within 2018.

This study was conducted in 2017 completive season for 14 weeks. They had about 52 training sessions and 22 games. They trained 5 to 8 times ranging for one to two hours, while they played 1 to 2 composed of two 45 minutes' periods.

Training and game data were collected at the end of each day. Recoding data in training session started from the beginning of warm-up and the end of recovery session. On the other hand, game data include warm-up, and the kick-off whistle to a final whistle/a player substituted (Eharmann et al., 2016). If a game goes into overtime, the extra time were added into game data.

The participants took HR monitors and GPS units before warm-up, and turn them on by themselves. In recovery session, a sport performance staff gathers these devices. After gathering these devices, the staff charged them and downloaded the data into analytic software.

Workload per week (defined as the mean of the distance each player covered per week) was determined for 14 weeks. The highest weekly value and the lowest weekly value over the 14 weeks was determined. Then these two values were used to do all comparisons of between IL with EL.

Data Collection Measures

Basic demographic information regarding age, height and weight were collected by team's staff.

Heart rate variables were collected by a Polar heart rate monitor (Polar Team 2, Polar Electro OY, Kempele, Finland). It recorded heart rate every 5 seconds. HR data were synchronized with the GPS unit and downloaded to GPS analytic software. Players were taught how to properly wear the HR monitors by dampening the electrodes on the chest strap, connecting the monitor to the strap, and by placing the strap/ monitor over the xiphoid process.

The rates of perceived exertion (RPE) was collected by the modified Borg scale, ranging from 0 to 10. One Sport Performance staff asked participants how hard a training session was.

External workload (EL) variables were determined by a Catapult Innovation GPS (Optimeye S5, Catapult Innovation, Melbourne, Australia) unit placed in a vest and worn between the shoulder blades on the players back. Prior to recovery sessions, the players were instructed to turn these devices on and off. Players were asked to wear the HR monitor and GPS units for every training session and every game for the entire season. The real time receiver (2.4 GHz radio frequency; firmware version 2.27) made by Catapult Innovation was used every training and game. The receiver was placed in the mid-line of a field during a practice or behind a team bench during a game. A laptop connected to the receiver via universal serial bus (USB). The data could be collected by wireless transmission ranging within 200 m.

After each training session and game, the data were downloaded to an analytic software (Openfield, Catapult Innovation, Melbourne, Australia). The researchers took the workload data form the software. The data were downloaded as an excel form and analyzed.

Session-RPE (S-RPE) (arbitrary units: AU) was calculated by multiplying S-RPE by training or game duration (min). A summated heart rate zone determined by the analytic software was used to identify TRIMP. TRIMP was calculated as follows : TRIMP = (< 65%HRmax (min) * 1.0) + (65-75%HRmax (min) * 1.2) + (75-85% HRmax (min) * 1.5) + (85-95%HRmax (min) * 2.2) + (>95%HRmax (min) * 4.5) + (Total Duration (min) * 9.0)) / 60.

Average HR (Avg-HR) (beats/min) was calculated by dividing total heart beats by time (min) (Owen et al., 2015). Also, heart rate data were used to determine work intensity into five categories or zones based on % of maximum HR (HRmax) achieved. HRmax were defined using a Polar heart rate monitor and 220 - age ± 10. The work intensity zones were based on the Avg-HR and time in minutes spent in each of the following five zones: Zone 1: ≤65% HRmax, Zone 2: 65-≤75%HRmax, Zone 3: 75-≤85%HRmax, Zone 4: 85-≤95%HRmax, and Zone 5: 95-100%HRmax. Lastly, any HR over 85% of HR max or the two highest HR zones were defined as being in the high HR (H-HR) zone. The HR categorization zones were based on past research by Owen et al (2015). If HR max did not meet the criteria, the all HR data were eliminated.

EL were obtained from the analytic software for each participant to determine workload. Total Distance (TD) in meters was determined by using the GPS unit to calculate the total overall distance a player runs during each practice or game. Average speed (Avg-Spd) in meters per minute (m/min) was calculated by dividing TD by total time (minute). TD (meters) was characterized into five distance groups using the total distance and average velocity attained. The five TD categories was defined used by estimated maximum speed (Max Speed) (Colby, Dawson, Heasman, Rogalski, & Gabbett, 2014; Gabbett, 2015): Zone1; 0-20%Max Speed, Zone 2; 20-40%Max Speed, Zone 3; 40-60%Max Speed, Zone 4; 60-80%Max Speed, and Zone 5; 80-100%Max Speed. Max Speed was decided via the speed during a practice or a game in this season. A final variable called high speed running (HSR) distance (m) was defined as a combination of the total meters completed in Zone 4 and Zone 5.

As a new variable, volume intensity index (VI index) was created to quantify the combined effect of both IL and EL. VI index was defined as the product of Ave-HR and TD.

For the second purpose, the IL and EL data 7 days before (Acute) and 21 days before (Chronic) injury occurs were collected in the injury group (Colby et al., 2014). Also, the Acute (weekly) and Chronic (three-week) season average in the non-injured group was obtained.

Data Selection and Cleaning

Data from training days and game days were separately analyzed. The data collection times for each group were standardized as follows: For all practice times (including the practice and warmup time prior to a game) the data collection time consisted of from the beginning of warm-up until the end of practice. For all game times, the data collection time mainly consisted of from a warm-up, a kick-off whistle to a final whistle or when a player is substituted (Eharmann et al., 2016). If a game went to overtime, the additional data were added to the game data. For any missing data (i.e., player does not turn on the GPS unit, sport performance staff cannot ask them RPE, technical errors and so on), the data were not added. The Sport Performance staff rinsed a vest and a strap out after all practices and games. Then, the vests and straps were dry at their office.

Injury Information

The criteria of injury were defined as follows: First, the team athletic trainer diagnosed injury as a soft tissue injury on lower limbs. Second, injury was muscular/ligamentous strains or tears and tendon problems (Gabbett &Ullah, 2012). Finally, the player missed more than one whole training session or one match or after soft-tissue injury occurred. When the injury meets all criteria, this study counted one injury (Ehrmann et al., 2016). This study did not consider the severity of the injuries on lower limbs.

Group Categorization

The participants were divided into two groups based on injury information in 2017 season: non-injured group and injured group. If soccer players meet the injury criteria, they were placed as injured-group.

Statistical Analysis

SPSS version 24.0 (IBM Corporation, New York, USA) was used to analyze data. Players were placed into two groups: Non-injured and Injured based on the number of soft tissue lower limb injuries they had during the season. Pearson correlation test and Spearman correlation test was conducted to identify the relationship between IL and EL. One-way ANOVA and Kruskal Wallis test were performed to analyze mean differences of IL (Avg-HR and H-HR zone) and EL (total distance, Avg-speed, and HSR) between the two groups. A P-value of ≤ 0.05 were considered significantly different. Data were expressed as mean ± standard deviation (SD), ranges (Min and Max) and a 95% confidence interval (95%CI).

Chapter 4

RESULTS

The purpose of this study was twofold: first, to identify the correlation between internal and external load of volume (S-RPE or TRIMP and TD), intensity (Avg-HR and Avg-Spd), and volume at higher intensity (H-HR Zone and HSR) generated during soccer play and practice in Division 1 female college soccer players and second, to identify any mean differences in either internal and/or external load between players who were injured and those who were not injured during the season.

The results from this study were described below for each main purpose. Twenty-three female soccer players participated in this study. Demographic data are summarized in Table 1.

Table 1
Demographic Data in All Subjects (n=23)

Variables	Mean	SD
Age (yr)	19.2	1.2
Height (cm)	168.2	7.3
Weight (kg)	64.0	7.8

Correlation between Internal load and External Load

It was hypothesized that there will be no significant correlation between internal and external load of volume (S-RPE or TRIMP and TD), intensity (Avg-HR and Avg-Spd), and volume at higher intensity (H-H Zone and HSR) in women college soccer.

Over the course of the season a total of 52 training sessions and 22 games were evaluated for 14 weeks. Table 2 indicates the range of mean total distance performed each week in meters. The data indicated that the total mean distance during the 12th week was highest at approximately 5986 meters per week and the lowest during the 4th week at 3677.5 meters per week.

Table 2
Weekly Mean Total Distance during the Season

Week	Mean (m)	SD	Min	Max
1st	5542.0	2237.8	2821.5	8684.5
2nd	4445.6	2221.6	2489.5	7241.0
3rd	4493.4	2848.8	2255.6	7140.2
4th	3677.5	3161.1	1869.9	9163.8
5th	4447.7	3105.2	2311.1	7062.1
6th	4823.9	3047.4	2852.9	7752.3
7th	4375.4	2861.2	2705.9	5758.0
8th	3711.4	2616.6	1888.6	6247.6
9th	5111.0	3706.9	2533.7	9417.2
10th	4322.7	3156.7	2040.2	6415.1
11th	4690.4	3227.1	2458.7	8615.6
12th	5985.9	3150.0	3799.9	9601.4
13th	4734.8	2892.1	3280.8	6322.7
14th	5515.8	2787.3	3632.9	7827.2

The data in the high and low weeks were merged and then this study investigated the correlation between internal and external load. Table 3 indicated that the mean of S-RPE, TRIMP, TD, Avg-HR, Avg-Spd, H-HR zone and HSR in the highest and the lowest week.

In the data collection, the study did not miss any external load in the highest and the lowest weeks (n = 172). In S-PRE, the data for one whole session were not collected because of time issues (n = 154). Also, TRIMP (n = 150), Avg-HR (n = 149) and H-HR zone (n = 152) because of technological and time issues.

Table 3

Mean Workload of the Highest and the Lowest Weeks in All Subjects

Variables	Mean	SD	Min	Max
S-PRE (AU)	373.3	316.5	33.7	1326.0
TRIMP (AU)	128.8	68.7	22.0	332.2
Avg-HR (beats/min)	143.2	18.8	100.6	178.7
H-HR Zone (min)	21.8	24.8	0.0	109.5
Total Distance (m)	4778.1	3352.3	666.6	14327.9
Average speed (m/min)	55.0	21.0	17.0	101.5
HSR (m)	30.4	53.4	0.0	323.0

Note. S-RPE: Session ratings of perceived exertion. TRIMP: Training impulse.
Avg-HR: Average heart rate.
H-HR zone: Higher heart rate zone (≥ 85% estimated maximum heart rate).
HSR: High speed running distance (≥60% maximum speed).

In the data collection, the study did not miss any external load in the highest and the lowest weeks (n = 172). In S-PRE, the data for one whole session were not collected because of time issues (n = 154). Also, TRIMP (n = 150), Avg-HR (n = 149) and H-HR zone (n = 152) because of technological and time issues.

A Spearman correlation test was used to examine the correlation between internal and external load of volume (S-RPE or TRIMP and TD), intensity (Avg-HR and Avg-Spd), and volume at higher intensity (H-H Zone and HSR) The results were summarized in Table 4.

Table 4

Correlation between Internal and External Load

Correlation	r
S-PRE and TD	0.82***
TRIMP and TD	0.75***
Avg-HR and Avg-Spd	0.80***
H-HR Zone and HSR	0.60***

Note. S-RPE: Session ratings of perceived exertion. TD: Total distance. TRIMP: Training impulse. Avg-HR: Average heart rate. Avg-Spd: Average speed. H-HR Zone: ≥85% estimated maximum heart rate. HSR: High speed running (≥60% maximum speed). ***<.001

The graphical depiction of these strong correlations are indicated in Figures 1, 2, 3 and 4. Figure 1 indicates that internal volume factor of S-RPE was significantly correlated with external volume factor of TD ($p < .001$, $r = .82$). Figure 2 points out that TRIMP had a significantly positive correlation with TD ($p < .001$, $r = .75$). Figure 3 illustrates that Avg-HR was significantly positively correlated with Avg-Spd ($p <.001$, $r = .80$). Figure 4 shows that the positive relationship between H-HR zone and HSR was significant.

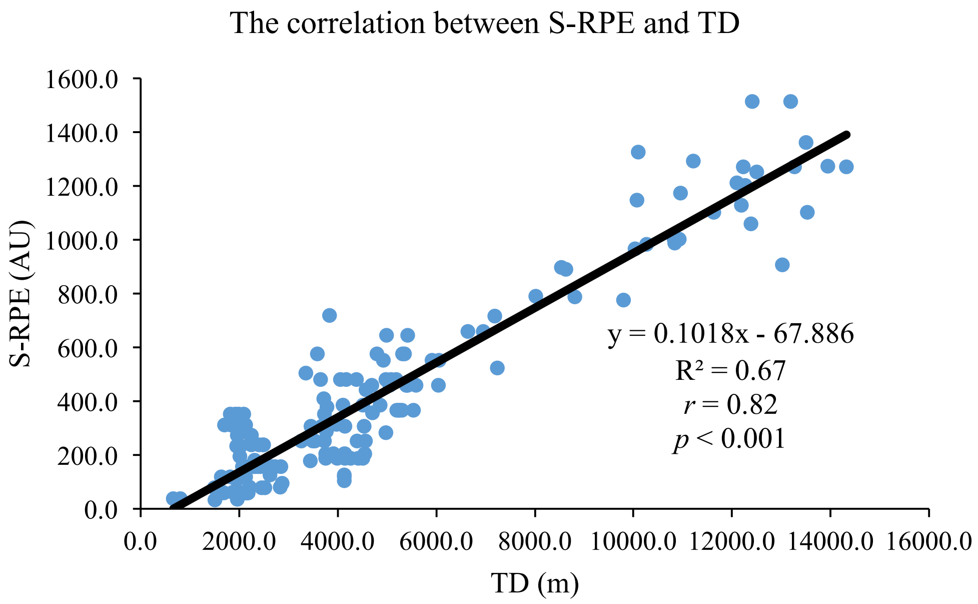

Figure 1. Spearman correlation between session ratings of perceived exertion (S-RPE) and total distance meters (TD).

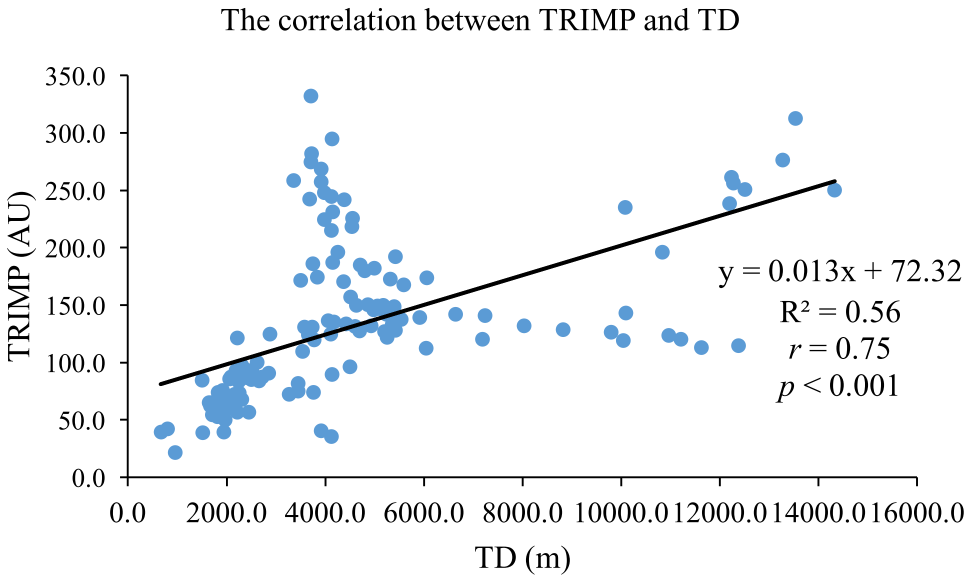

Figure 2. Spearman correlation between training impulse (TRIMP) and total distance (TD).

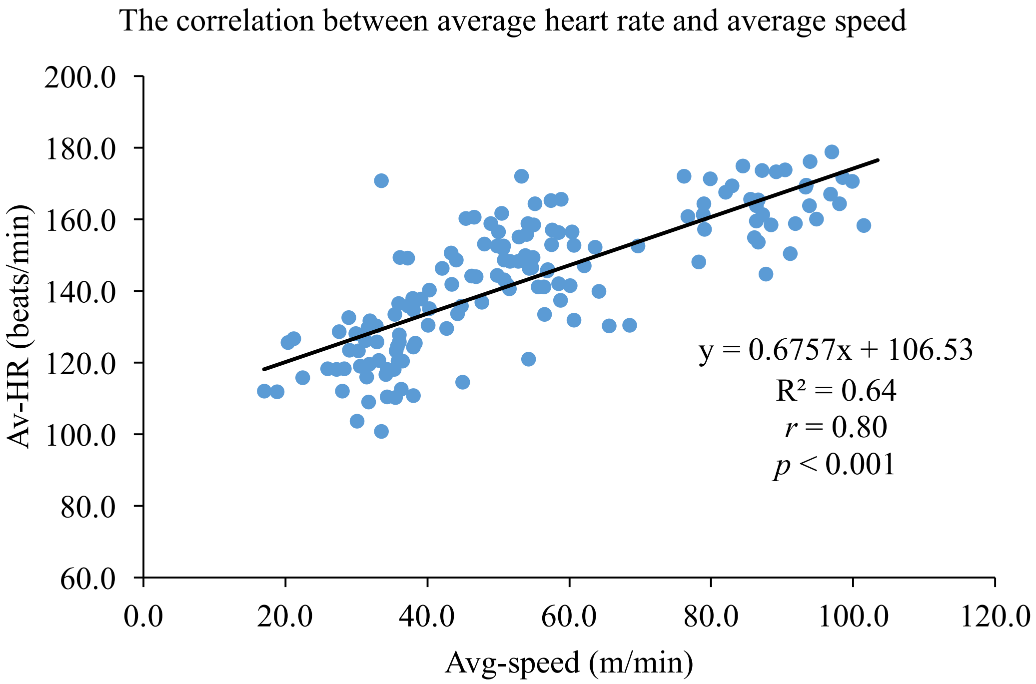

Figure 3. Spearman correlation between average heart rate (Avg-HR) and average speed (Avg-Spd).

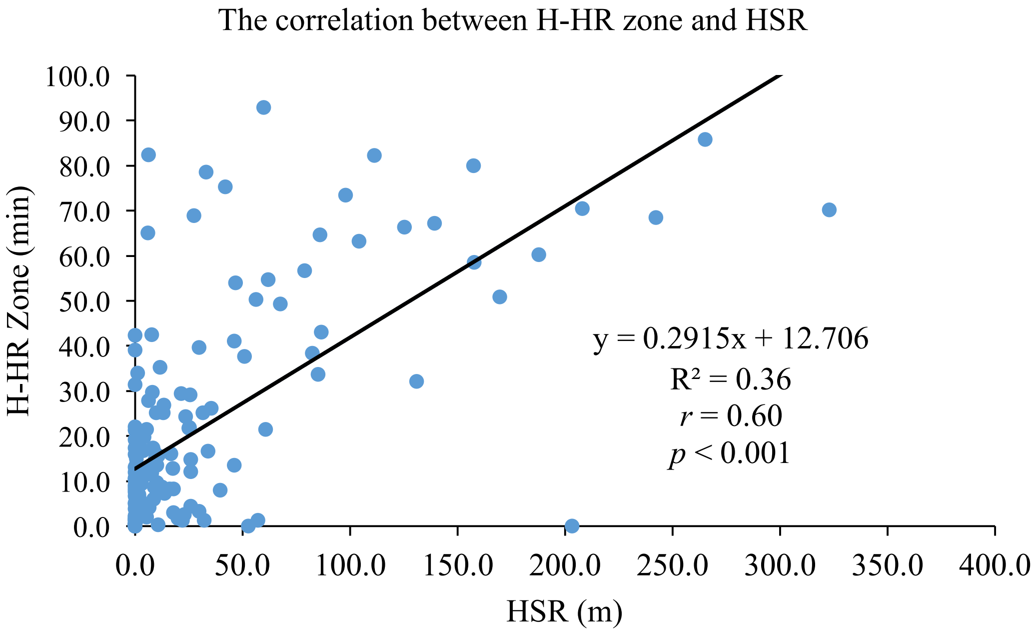

Figure 4. Spearman correlation between higher heart rate zone (H-HR Zone) and high speed running (HSR).

The mean difference between non-injured and injured groups

The hypothesis in this study was that there will be no mean differences of internal (i.e. session ratings of perceived exertion, training impulse, average heart rate, and time spent at higher heart rate zone) and external (total distance, average speed, high speed running distance, and running speed) load between non-injured and injured groups to predict risk of soft tissue injury on lower limbs in college female soccer players? In this study, the criteria of injury were followings: First, the injury was a soft tissue injury on lower limbs diagnosed by the team athletic trainer. Second, the injury was muscular/ligament strains or tears and tendinous issues. Finally, the player could not complete more than one whole session because of the injury. Seven lower limb injuries were found during the in-season (Table 5). Four of them were non-contact injuries while the rest were contact injuries. The most frequent injury was muscle strain on hip joint in this study, followed by medial collateral ligament sprain on knee joint.

Table 5

Injury Summary during In-Season.

Category	Hip (n)	Knee (n)	Ankle (n)	Foot (n)	Total (n)
Contact (n)	0	3	0	0	3
Non-contact (n)	3	0	1	0	4
Total (n)	3	3	1	0	7

One-way of ANOVA was performed to compare the difference between the groups in acute workload of TRIMP, H-HR zone, Avg-HR, Avg-Spd, and HSR, chronic workload of TRIMP, S-RPE, Avg-HR, H-HR zone, Max HR, Avg-Spd, HSR and MAX Spd and acute chronic workload of TD. Acute workload of S-RPE, HR

MAX, TD, and MAX Spd, Chronic workload of TD and acute chronic workload ratio in S-RPE, TRIMP, Avg-HR, H-HR zone, Max HR, HSR, MAX Spd were analyzed by Kruskal-Wallis Test. Overall average workload was summarized in Table 6.

Table 6

The Mean Workload of All Weeks in the All Subjects

Workload	Mean	SD	Range Min	Max
S-RPE (AU)	416.1	99.7	227.7	551.0
TRIMPH (AU)	123.2	16.7	101.9	164.9
Average HR (beats/min)	144.6	5.5	136.1	151.1
H-HR zone (min)	21.5	5.2	13.8	31.9
Max HR (beats/min)	196.0	4.2	189.8	201.7
Total distance (m)	4705.6	659.5	3677.5	5985.9
Average speed (m/min)	56.3	6.5	46.2	68.8
HSR (m)	37.7	11.9	24.0	73.2
Max speed (m/s)	6.2	0.3	5.8	6.6
IV Index (AU)	736.1	135.0	543.1	1047.0

Note. S-RPE: Session ratings of perceived exertion. TRIMP: Training impulse.
Avg-HR: Average heart rate. Max HR: Estimated Maximal heart rate.
H-HR zone: High heart rate zone (≥85% of Max HR). Max speed: Estimated Maximum
Speed. HSR: high speed running distance (≥60% of Max Speed).

Acute workload was defined as either average weekly workload in the non-injured group or seven days before the injury happened in the injured group. Acute workloads in the Non-injured and Injured groups were summarized in Table 7. The results indicated that the Avg-HR in the injured group was significantly higher than the non-injured by 8.9 beats (*p* = .001; Figure 5). The other variables between the groups were not significantly different. Individual acute workloads in the injured groups were summarized in the Table 8.

Table 7

The Mean Acute Workload in the non-Injured and the injured Groups

	non-injured				*injured*				p
			Range				Range		
Workload	Mean	SD	Min - Max		Mean	SD	Min - Max		
S-RPE (AU)	392.6	93.6	250.8	443.4	760.3	261.4	201.4	944.8	0.15
TRIMPH (AU)	121.5	18.8	93.4	131.7	168.1	103.1	84.2	181.0	0.25
Average HR (beats/min)	143.8	5.0	133.0	146.5	157.9*	147.6	146.8	163.7	0.01
Max HR (beats/min)	197.0	6.5	188.1	200.5	191.5	4.4	198.5	183.8	0.63
Higher H-zone (min)	20.3	6.7	9.9	23.9	33.9	18.2	13.4	36.3	0.11
Total distance (m)	4613.7	1035.2	3008.3	5176.4	6298.3	4066.8	2409.0	6238.1	0.12
Average Speed (m/min)	56.4	5.6	43.4	59.5	64.6	51.6	46.6	68.8	0.60
Max Speed (m/s)	6.3	0.3	5.6	6.4	6.6	6.0	5.7	6.7	0.42
High speed distance (m)	35.7	20.4	6.4	46.8	68.4	26.6	2.8	92.3	0.29
VI Index (AU)	662.7	160.0	413.2	749.7	894.0	690.8	361	971	0.16

Note. S-RPE: Session ratings of perceived exertion. TRIMP: Training impulse. Avg-HR: Average heart rate.

Max HR: Estimated maximal heart rate. H-HR zone: High heart rate zone (≥ 85% of heart rate max).

Max speed: Estimated maximum speed. HSR: High speed running speed (≥ 60%Max Speed). VI Index: Volume intensity index.

*: $p < .05$

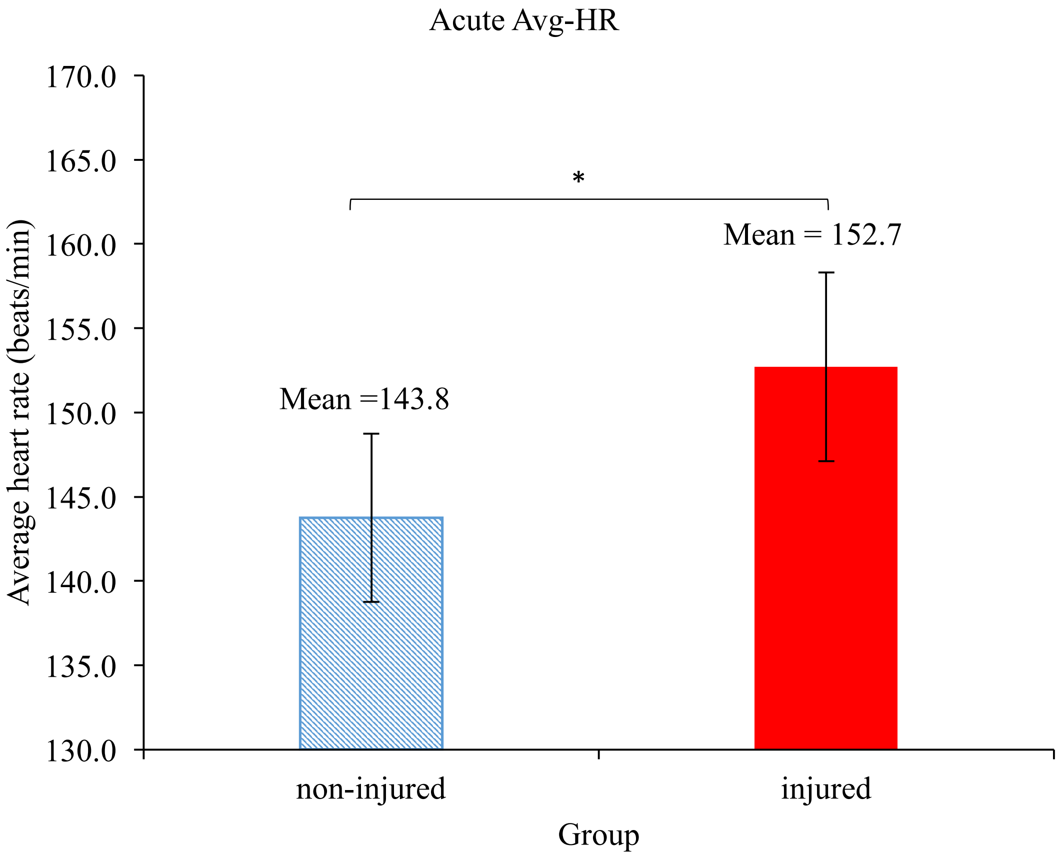

Figure 5. The mean difference of acute workload of average heart rate (Avg-HR) between non-injured and injured groups.

Note. *p < .05.

Table 8

Individual Acute Workload in the Injured Group (n=7)

ID	1	2	3	4	5	6	7	Mean
S-RPE (AU)	944.8	234.2	753.8	383.6	525.6	201.4	532.4	510.8
TRIMPH (AU)	181.0	176.4	132.9	110.3	145.8	84.2	118.5	135.6
Average HR (beats/min)	163.7	152.6	146.8	153.3	148.4	149.7	154.6	152.7
Max HR (beats/min)	191.0	191.8	183.8	191.5	190.0	193.8	198.5	191.5
Higher H-zone (min)	33.5	36.3	25.5	23.4	32.3	13.4	18.0	26.1
Total distance (m)	5933.0	6087.3	6011.1	6238.1	5904.7	2409.0	3694.4	5182.5
Average Speed (m/min)	57.4	68.8	54.1	63.0	67.7	49.3	46.6	58.1
Max Speed (m/s)	6.7	6.4	6.4	6.6	6.7	5.8	5.7	6.3
High speed distance (m)	69.9	92.3	47.2	47.2	32.5	2.8	40.7	47.5
VI Index (AU)	971.0	571.1	929.2	882.3	956.2	360.6	876.4	792.4

Note. S-RPE: Session ratings of perceived exertion. TRIMP: Training impulse. Avg-HR: Average heart rate.

Max HR: Estimated maximal heart rate. H-HR zone: High heart rate zone (≥ 85% of heart rate max).

Max speed: Estimated maximum speed. HSR: High speed running speed (≥ 60%Max Speed). VI Index: Volume intensity index.

In this study, Chronic workload was There were no significant mean differences between the non-injured and injured groups when comparing chronic workload, (Table 9). With regard to the individual chronic workloads, the injure workloads were summarized in the Table 10.

Table 9

The Mean Chronic Workload in the non-Injured and the injured Groups

	non-injured				*injured*				
			Range				Range		p
Workload	Mean	SD	Min - Max		Mean	SD	Min - Max		
S-RPE (AU)	397.1	100.9	259.6	554.5	507.8	142.7	250.7	650.6	0.07
TRIMPH (AU)	119.8	20.8	88.5	150.6	130.3	17.4	96.4	143.8	0.30
Average HR (beats/min)	143.7	7.4	132.1	155.6	147.0	3.7	139.8	150.5	0.32
Max HR (beats/min)	196.6	6.6	187.5	210.4	191.2	2.4	188.6	195.1	0.79
Higher H-zone (min)	20.0	7.1	9.7	32.0	23.0	5.3	15.4	28.5	0.37
Total distance (m)	4514.7	1083.4	2890.1	5986.9	4978.1	1122.4	2766.1	5755.3	0.60
Average Speed (m/min)	55.7	5.5	43.8	65.6	54.7	7.1	49.0	60.4	0.76
Max Speed (m/s)	6.3	0.3	5.7	6.6	6.4	0.3	6.0	6.8	0.28
High speed distance (m)	33.9	19.7	7.3	63.4	46.5	22.5	11.7	79.4	0.23
VI Index (AU)	650.2	162.3	397.7	883.2	731.6	153.2	410.8	865.9	0.22

Note. S-RPE: Session ratings of perceived exertion. TRIMP: Training impulse. Avg-HR: Average heart rate.

Max HR: Estimated maximal heart rate. H-HR zone: High heart rate zone (≥ 85% of heart rate max).

Max speed: Estimated maximum speed. HSR: High speed running speed (≥ 60%Max Speed). VI Index: Volume

Table 10

Individual Chronic Workload in the Injured Group (n=6)

ID	1	2	3	4	5	6	Mean
S-RPE (AU)	650.6	482.3	622.3	546.1	495.1	250.7	507.8
TRIMPH (AU)	143.8	138.4	130.9	131.1	141.1	96.4	130.3
Average HR (beats/min)	147.0	139.8	148.0	150.5	148.1	148.5	147.0
Max HR (beats/min)	192.8	189.6	188.6	191.0	190.2	195.1	191.2
Higher H-zone (min)	19.2	25.6	21.2	28.5	28.0	15.4	23.0
Total distance (m)	5054.1	5084.6	5626.4	5755.3	5582.0	2766.1	4978.1
Average Speed (m/min)	47.2	56.6	55.6	58.3	64.8	45.9	54.7
Max Speed (m/s)	6.4	6.6	6.5	6.4	6.8	6.0	6.4
High speed distance (m)	52.8	79.4	52.9	47.6	34.4	11.7	46.5
VI Index (AU)	742.8	710.8	832.5	865.9	410.8	826.9	731.6

Note. S-RPE: Session ratings of perceived exertion. TRIMP: Training impulse. Avg-HR: Average heart rate.

Max HR: Estimated maximal heart rate. H-HR zone: High heart rate zone (≥ 85% of heart rate max).

Max speed: Estimated maximum speed. HSR: High speed running speed (≥ 60%Max Speed). VI Index: Volume intensity

Finally, the study investigated the mean AC ratio differences of internal and external load between the non-injured and the injured groups (Table 11). The results showed that the AC ratio of Avg-Spd and VI index in the injured were significantly higher than in the non-injured (*p* = .024; Figure 6 and *p* = .035; Figure 7). Also, the Injured group showed a trend to having a significantly higher mean TD value than the non-injured (*p* = .056; Figure 8). Table 12 indicated the individual AC ratio in the injured group. Figure 9 to 18 showed

Table 11

The Acute Chronic Workload Ratio in the non-Injured and the injured Groups

	non-injured				*injured*				
			Range				Range		p
Workload	Mean	SD	Min - Max		Mean	SD	Min - Max		
S-RPE	0.95	0.04	0.82	0.99	0.95	0.36	0.49	1.45	1.00
TRIMPH	1.01	0.04	0.94	1.07	1.05	0.18	0.84	1.27	0.57
Average HR	0.99	0.03	0.91	1.01	1.04	0.05	0.99	1.11	0.20
Max HR	0.99	0.03	0.92	1.01	1.01	0.03	0.97	1.01	0.30
Higher H-zone	1.03	0.06	0.87	1.11	1.20	0.35	0.82	1.75	0.24
Total distance	1.00	0.04	0.90	1.05	1.08	0.12	0.87	1.20	0.06
Average Speed	1.01	0.04	0.89	1.04	1.1*	0.10	0.97	1.22	0.02
Max Speed	1.00	0.02	0.92	1.01	1.00	0.04	0.97	1.06	0.44
High speed distance	1.00	0.06	0.89	1.09	0.93	0.37	0.24	1.32	0.69
VI Index	1.01	0.04	0.90	1.06	1.12*	0.16	0.88	1.31	0.04

Note. S-RPE: Session ratings of perceived exertion. TRIMP: Training impulse. Avg-HR: Average heart rate.

Max HR: Estimated maximal heart rate. H-HR zone: High heart rate zone (≥ 85% of heart rate max).

Max speed: Estimated maximum speed. HSR: High speed running speed (≥ 60%Max Speed). VI Index: Volume intensity index.

*: $p < .05$

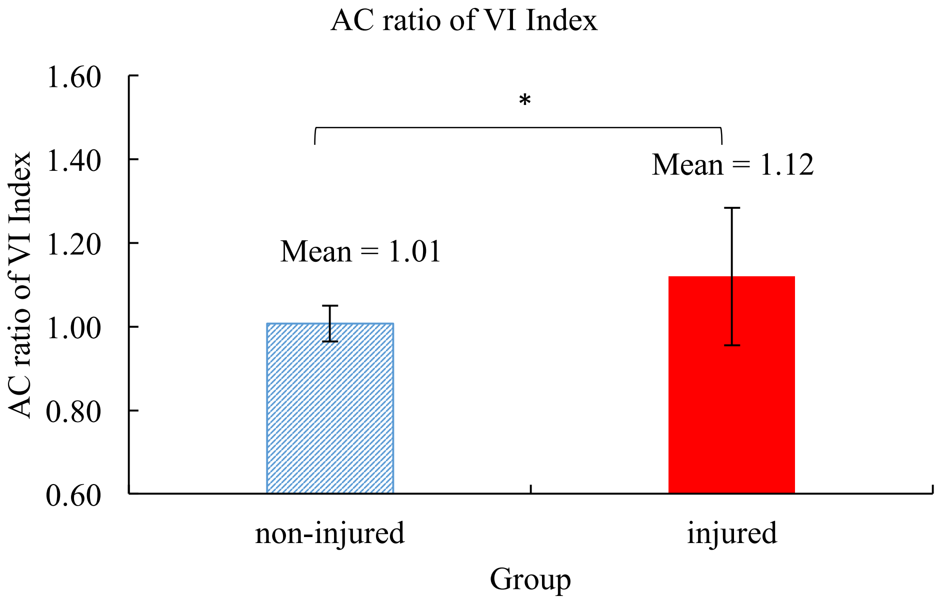

Figure 6. The mean difference of Acute Chronic Workload Ratio (AC ratio) of average speed (Avg-Spd) between non-injured and injured groups.

Note. *: $p < .05$.

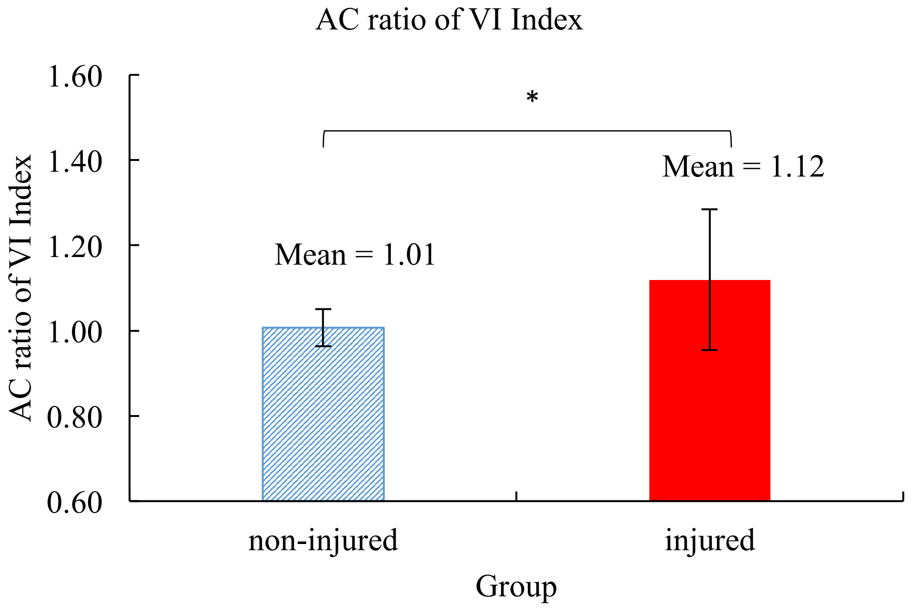

Figure 7. The mean difference of Acute Chronic Workload Ratio (AC ratio) of Volume Intensity Index (VI Index) between non-injured and injured groups.

Note. *: $p < .05$.

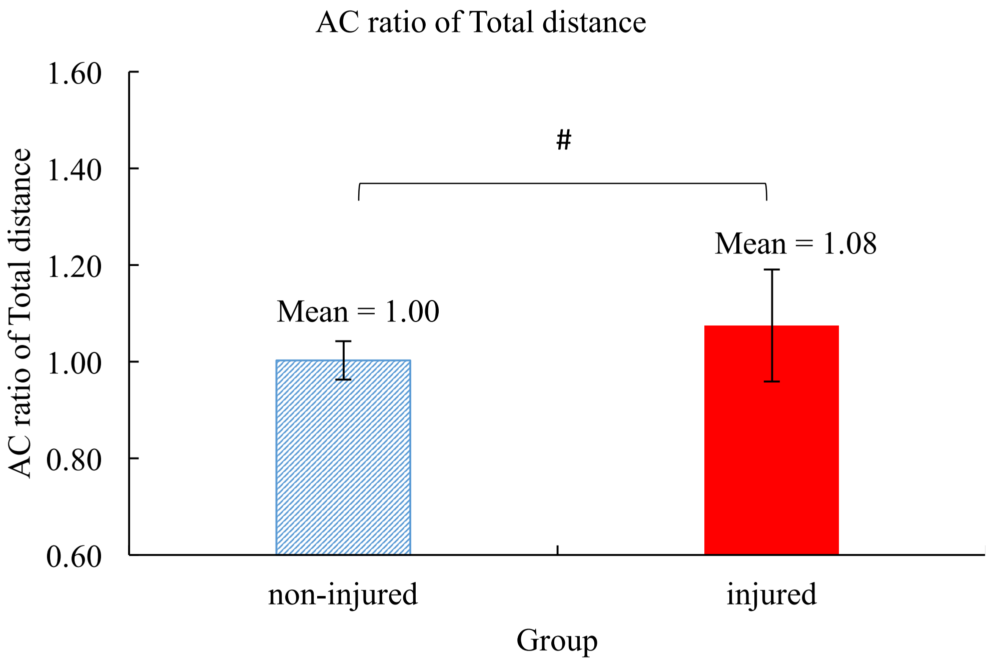

Figure 8. The mean difference of Acute Chronic Workload Ratio (AC ratio) of Total distance (TD) between non-injured and injured groups.

Note. #: p = .056.

Table 12

Individual Acute Chronic Workload Ratio in the Injured Group (n=6)

ID	1	2	3	4	5	6	Mean
S-RPE (AU)	1.45	0.49	1.21	0.70	1.06	0.80	0.95
TRIMPH (AU)	1.26	1.27	1.02	0.84	1.03	0.87	1.05
Average HR (beats/min)	1.11	1.09	0.99	1.02	1.00	1.01	1.04
Max HR (beats/min)	0.99	1.01	0.97	1.00	1.00	0.99	1.00
Higher H-zone (min)	1.75	1.42	1.20	0.82	1.16	0.87	1.20
Total distance (m)	1.17	1.20	1.07	1.08	1.06	0.87	1.08
Average Speed (m/min)	1.22	1.22	0.97	1.08	1.04	1.07	1.10
Max Speed (m/s)	1.06	0.98	0.98	1.04	0.99	0.97	1.00
High speed distance (m)	1.32	1.16	0.89	0.99	0.94	0.24	0.93
VI Index (AU)	1.31	1.31	1.06	1.10	0.88	1.06	1.12

Note. S-RPE: Session ratings of perceived exertion. TRIMP: Training impulse. Avg-HR: Average heart rate.

Max HR: Estimated maximal heart rate. H-HR zone: High heart rate zone (≥ 85% of heart rate max).

Max speed: Estimated maximum speed. HSR: High speed running speed (≥ 60%Max Speed). VI Index: Volume intensity

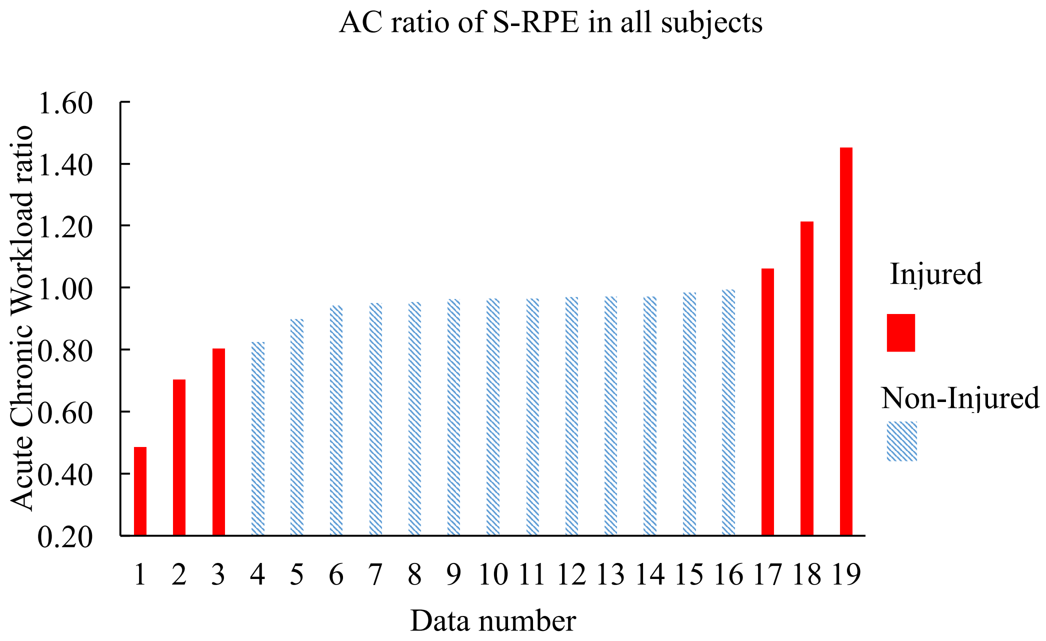

Figure 9. The Acute Chronic Workload Ratio (AC ratio) of the session ratings of perceived exertion (S-RPE) in all subjects.

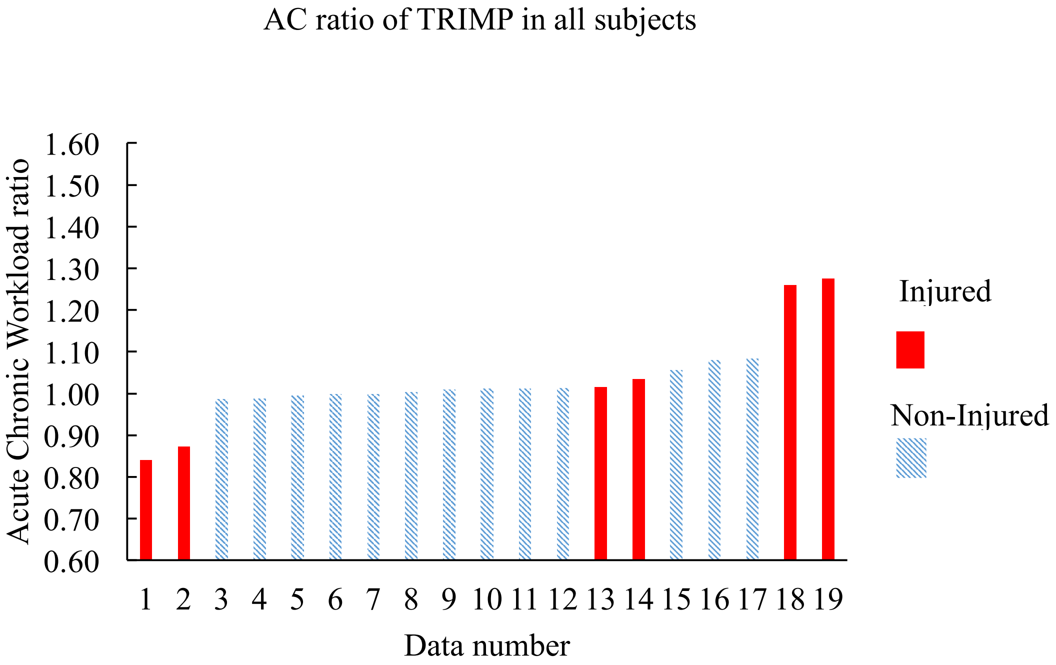

Figure 10. The Acute Chronic Workload Ratio (AC ratio) of training impulse (TRIMP) in all subjects.

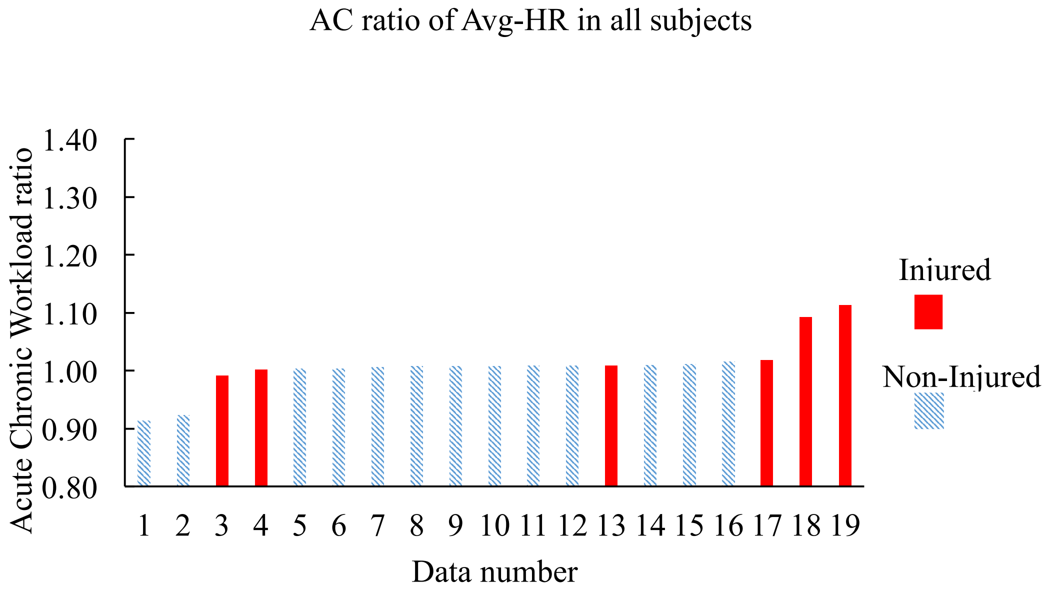

Figure 11. The Acute Chronic Workload Ratio (AC ratio) of average heart rate (Avg-HR) in all subjects.

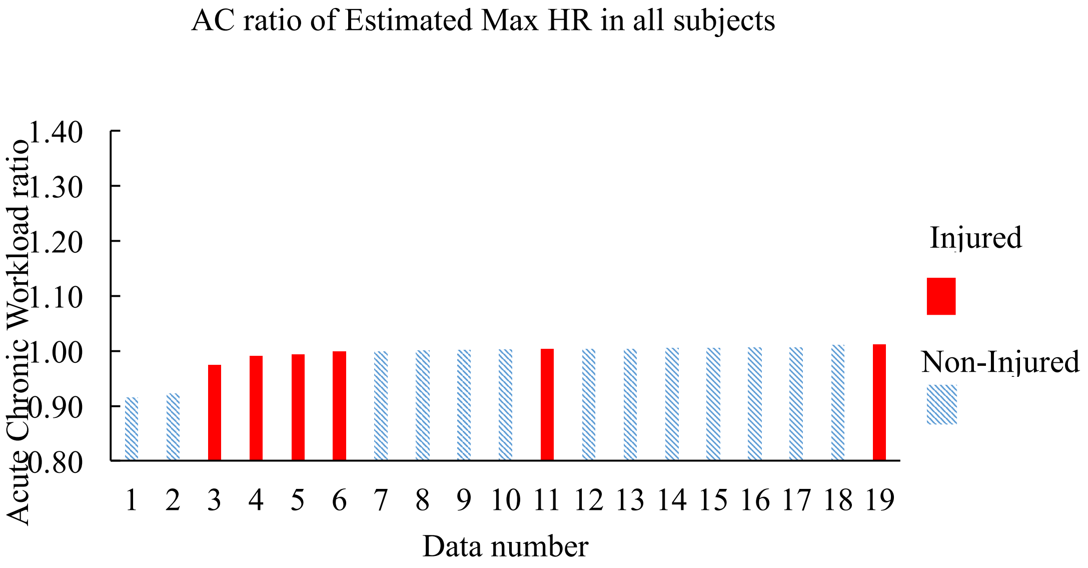

Figure 12. The Acute Chronic Workload Ratio (AC ratio) of estimated maximum HR (Max HR) in all subjects.

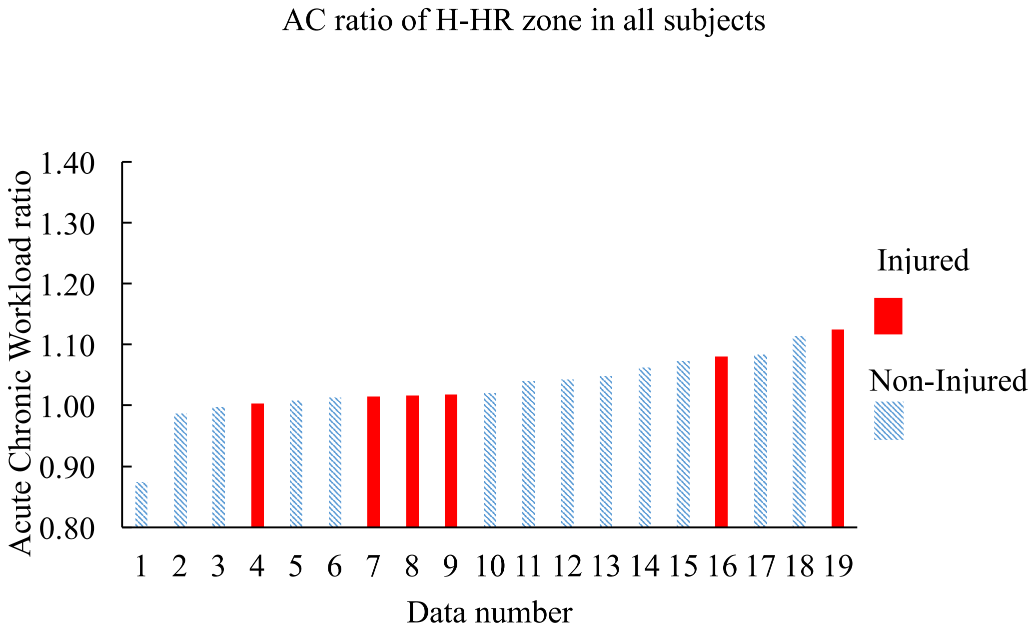

Figure 13. The Acute Chronic Workload Ratio (AC ratio) of higher heart rate zone (H-HR zone) in all subjects.

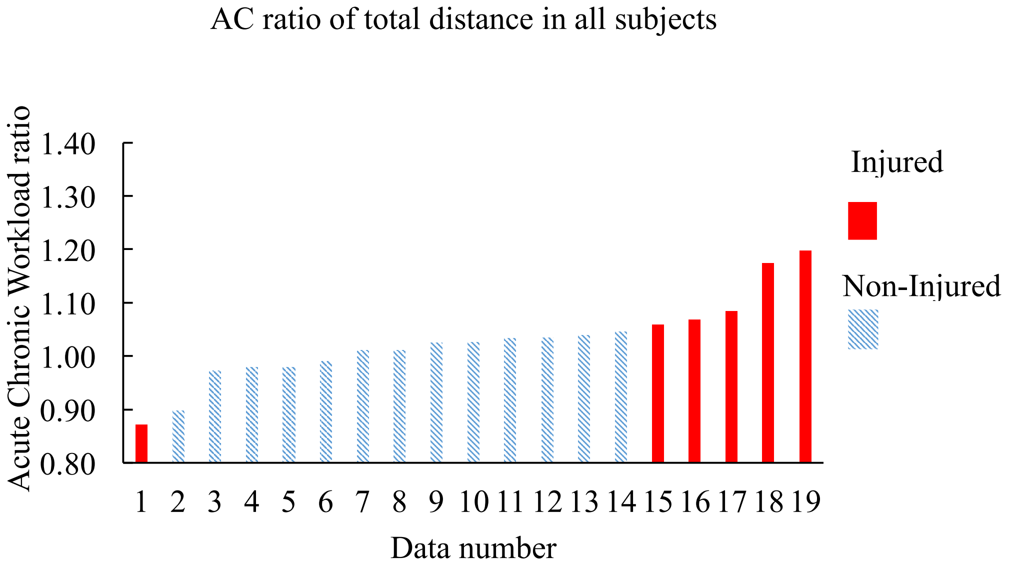

Figure 14. The Acute Chronic Workload Ratio (AC ratio) of total distance in all subjects.

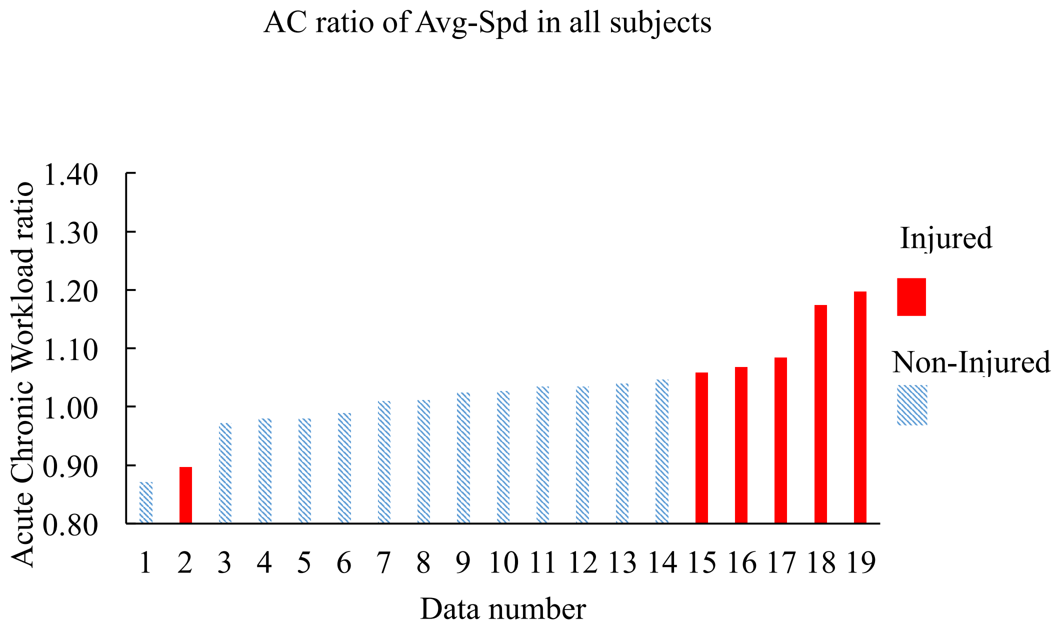

Figure 15. The Acute Chronic Workload Ratio (AC ratio) of average speed (Avg-Spd) in all subjects.

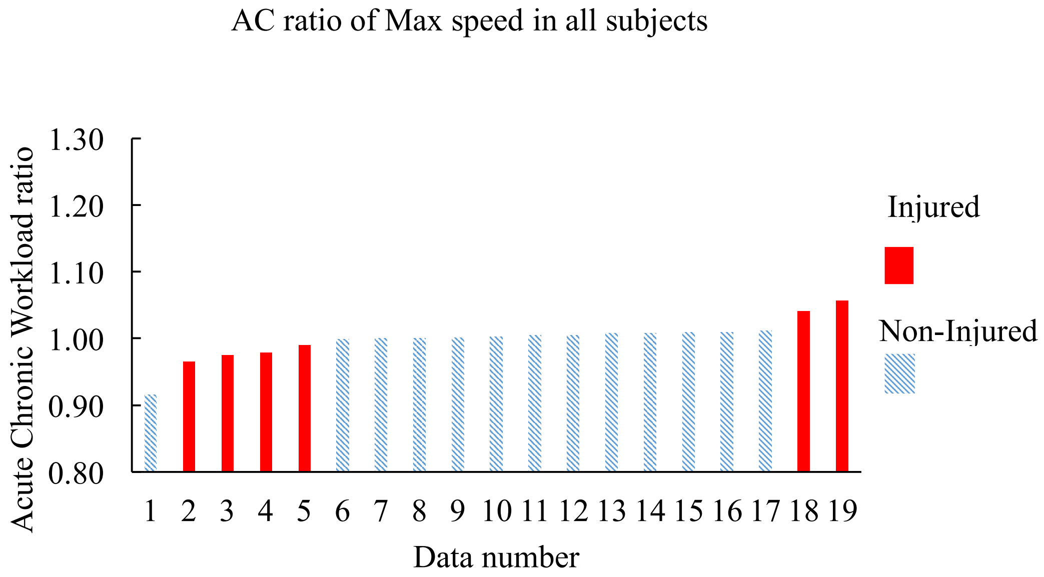

Figure 16. The Acute Chronic Workload Ratio (AC ratio) of estimated maximum speed (Max speed) in all subjects.

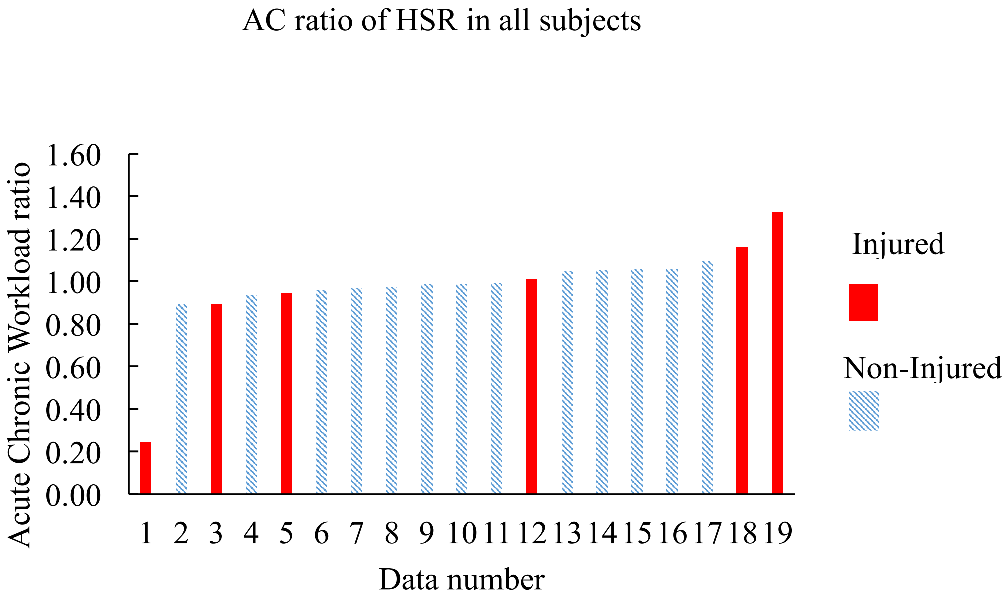

Figure 17. The Acute Chronic Workload Ratio (AC ratio) of high speed running distance (HSR) in all subjects.

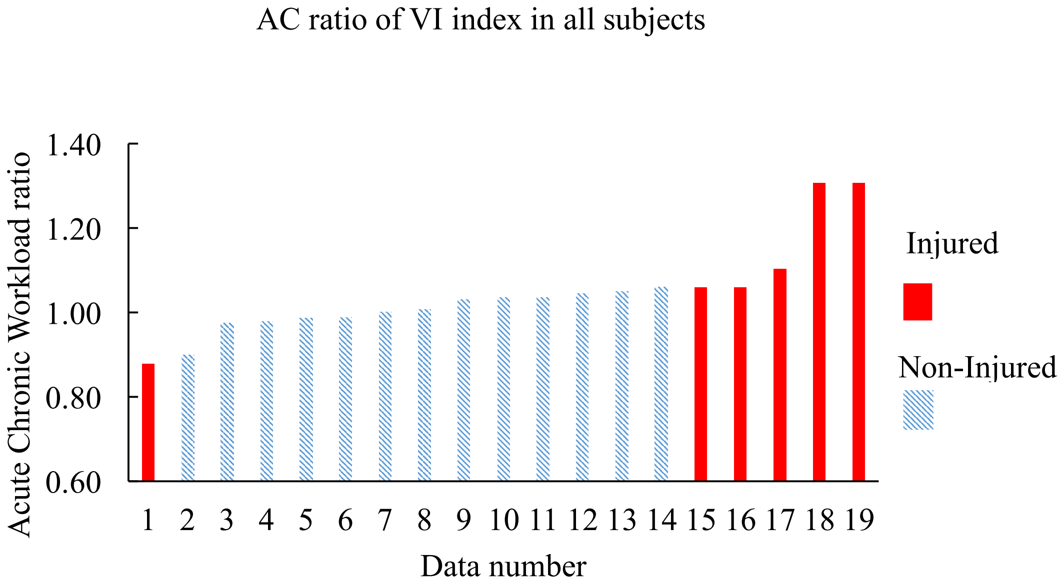

Figure 18. The Acute Chronic Workload Ratio (AC ratio) of volume intensity index (VI index) in all subjects.

Chapter 5

DISCUSSION

This study sought to identify the correlation between internal and external load with regard to volume variables (i.e., session ratings of perceived exertion and total distance, and training impulse and total distance), intensity variables (i.e., average heart rate and average speed) and high intensity volume variables (i.e., time at higher heart rate zone and distance at higher speed) in college female soccer players. In addition differences between injured and non-injured players were compared with regard to internal and external load.

Although it was hypothesized that there would be no significant associations between internal and external load in college female soccer players, the findings of this study indicated that several variables were significantly correlated. Notably, there were significant correlations between S-PRE and TD, TRIMP and TD, Avg-HR and Avg-Spd, and H-HR zone and HSR.

No previous studies have examined the correlation between S-RPE and TD in the female athletes. Past studies using male athletes were similar to this study in that S-RPE and TD were significantly correlated (Scott et al., 2013; Vickery, Dascombe, & Duffield, 2017). The findings of this study suggest that because a correlation between these variables is significant in these women athletes, then the athletic training staff may have more choice when attempting to monitor workload volume. Scott et al., (2013) reported that S-RPE was strongly associated with total distance (TD) (r = .80) in professional Australian soccer players. Also, Vickery, Dascombe and Duffield (2017) found a strong correlation between S-RPE and TD in batsman (r = .74), and a very strong correlation between these variables in medium-fast bowlers (r = .87) in male cricket players. Thus, if team resources are limited, then the strong correlation between S-RPE and TD suggests that simply the ability to measure S-RPE may be an adequate surrogate to estimate training volume.

One interesting finding from this study concerned the correlations between TRIMP and TD. Past studies (Wallace, Slattery & Coutts, 2009) have indicated that S-RPE was significantly correlated to TRIMP. Wallace, Slattery and Coutts (2009) indicated that Banister's TRIMP (Banister, 1991) and Edwards's TRIMP (Edwards, 1993) scores were significantly correlated to S-RPE ($r = .74$ and .75) in experienced swimmers. However, in this study, as indicated in Figure 2, there was a bi-modal distribution in the relationship between TRIMP and TD such that the correlation was not linear. TRIMP was associated with TD only at the high and low ends of TD. Although the scatter plots for TRIMP and TD should have been similar to that of S-RPE and TD, in fact TRIMP was not correlated to TD. It is speculated that the reason for this discrepancy was because of the sustained time the athletes were engaged in exercise. Heart rate values typically increase when exercise time is prolonged even if workload is steady. This phenomena, known as cardiovascular drift, is characterized by increases in heart rate with decreases in stroke volume. This is especially likely when exercising in the heat. Thus, although cardiac output is the same, the heart rate values become increasing high resulting in a very high intensity. In this case, one must reduce the workload to avoid fatigue. Perhaps the distinctive relationship between TRIMP and TD in this study reflects the onset of dehydration in these women. More physiological information (such as urine specific gravity) and/or water intake would need to be assessed to determine whether this relationship actually was an indication of dehydration.

The relationships between IL and EL variables in this study indicated a lot of variability. Specifically, there were outliers in data concerning the volume of work performed at a high intensity. The data indicated that it could be difficult for female soccer players to reach 60% of their maximum speed. In other words, on average the women in this study did not typically push themselves to sprint at high speeds during training or even during game play. Interestingly, the high speed running zone in this study was based on relative speed rather than on absolute speed as is typically done (Bowen et al., 2017; Carey et al., 2016; Malone et al., 2017; Murray, Gabbett, Townshend, & Blanch, 2017). Although others (Colby et al., 2014; Gabbett, 2015) have used relative speed rather than absolute speed to demark these speed zones this characterization adds to the variability of the data. Lastly, playing positions and player's skill level also influence the sprint profiles in soccer. Salvo et al., (2010) showed that a wide midfielder recorded the most sprint frequencies (the speed above 25.2 km per hour), followed by attackers and wide defenders. Mohr, Krustrup, Andersson, Kirkendal and Bangsbo (2008) indicated that soccer players in the United States covered more sprinting distance as compared to the best Danish and Sweden teams. High zone categorization, playing positions and player's skill levels could affect the correlation between IL and EL in volume at a high intensity as well.

Future research will need to control for the effect of exercise time on the TRIMP and TD correlation. In this study, the data from the highest and the lowest weeks were combined. In fact, on average during the highest week, the players participated in three training sessions and two games while during the lowest week there were four training sessions and one game. For most of the women, the average TD in the week with two games was higher than that with one game. Also, future studies will reset the high speed running zone if relative speed is used. Most players could not cover the distances above 60% of their maximum speed.

As noted previously, the second purpose of this study was to compare the mean differences in internal and external load between the non-injured and the injured players. It was hypothesized that there would be no significant group differences in IL or EL between non-injured and injured players. In fact, the results from this study indicated that the injured group had significantly higher acute IL values such that mean Avg-HR values were higher than those in the non-injured group. Additionally, the acute to chronic ratio for Avg-Spd and the VI index in the injured group were significantly higher than that in the non-injured group. The injured groups relatively accumulated either the higher weekly average workloads than the 3-week average, or the lower chronic 3-week average workload than the weekly average.

One of the novel findings of this study was that acute Avg-HR was significantly higher in the injured group compared to the non-injured group. As a whole, the injured players recorded higher mean Avg-HR than the values recorded by the non-injured group. Previous article (Vanrenterghem and Robinson, 2017) supports the concept that HR is a valid indicator of workload and cardiovascular intensity. In this study, the injured players had higher Ave-HR values for the seven days prior to getting injured. Results from Owen et al., (2015) found that those who spent a greater overall time period at a HR value between 85 to 89% HR max had significantly increased injury risk in a game (OR = 1.82, $p = 0.02$). Also, they indicated that the group sustaining an injury spent much time at above 90% HR max for four weeks ($p = 0.04$). In this study, there were no differences between injured and non-injured players regarding the number of minutes at a high-HR zone. This is likely because two injured players recorded extremely low number of minutes at at high HR (i.e., 13.4 and 18.0 minutes respectively). Thus, these two scores would have reduced the statistical significance between groups. The data indicate that the acute Avg-HR and the number of minutes at ta high HR zone might be important variables with regard to potential injury in college female soccer players.

This research provided new results about the significant differences of AC ratio in Avg-Spd between the injured and the non-injured groups. In this study, the AC ratio of Avg-Spd and VI Index in the injured group was higher than the non-injured. Ehrmann et al., (2016) indicated that weekly and 4-week Avg-Spd in the injured group were significantly higher than the season average in 19 male professional soccer players in Australia (p = 0.008 for both comparisons). When the AC ratio is above 1.0, players are exposed to more overall and intensive stress on their body. Vanrenterghem & Robinson, (2017) recently suggested that Avg-Spd might be a good representation of energy consumption. The players with a high AC ratio of Avg-Spd would use more energy during trainings and games. Thus, the injured group may have been in more fatigued state compared with the non-injured. In this study, acute Avg-Spd between the injured and the non-injured groups was not significantly different. However, two of the injured women had acute and chronic Avg-Spd, much lower than speeds than their group average by approximately 10 meters per minute. This could mean that these women lacked the ability to run at the level of speed achieved by the majority of the other women athletes.

Again, in this study the high sped running distance (HSR) was not significantly different between non-injured and injured groups. However, as noted previously, there was a problem with the how speed zones were categorized. Past studies (Bowen et al., 2017; Colby et al., 2014; Malone et al., 2017) demonstrated that HSR was able to predict injury and suggested that HSR would be useful for preventing injury in Australian Football, and professional soccer as a whole. The college female soccer players in this study did not have the ability to reach a running speed above 60% of their maximum speed. However, Colby et al., (2014) claimed that a 3-week moderate sprint distance (75% of maximum speed) (864 to 1453 meters) reduced injury risk in elite Australian footballers (OR = 0.229, *p* = 0.045). Ehrmann et al., (2016) showed that there was no significant change in 1-week and 4-week high intensity running (the speed from 14.3 to 19.7 kilometers per hour) difference between the injured and the non-injured groups. Bowen et al., (2017) found that accumulating increasing time of HSR (856–1449 meters) was associated with high injury risk (RR = 1.73, *p* = 0.029). Malone et al., (2017) also demonstrated that the group with 1-week HSR (the speed from 14.4 to 19.8 kilometers per hour) accumulation between 750 and 1025 meters had the highest odds ratio in elite European soccer players (OR = 5.02, *p* = 0.006). From the studies, HSR should be one of vital indicators for not sustaining an injury. Very high or low HSR accumulation could increase injury risk as well.

When further examining the data, an interesting finding was revealed. Those who were injured, were characterized into two types of workloads: either very high or very low workload groups. The majority of the injured women had very high workloads and had higher IL or EL values than the overall mean of the injured group. For these women, injury was sustained toward the middle or end of the season. On the other hand, a few injured players had workloads far lower than the group mean. For these players injury occurred in the beginning of the in-season (1st week and 6th week). Past studies suggested that very high acute workload, chronic workload, and AC ratio would exponentially increase injury risk. Rogalski et al., (2012) found that acute high (1750 to 2250 AU) and very high (>2250 AU) S-RPE was associated with high injury risk during the season in elite Australian Footballers (OR = 2.44, p = 0.007; OR = 3.38, p = 0.001). Bowen et al., (2017) revealed that high TD for 4-week

(112244 to 143917 meters accumulated) significantly increased injury risk (RR = 1.64, $p = 0.031$). In addition, acute moderate HSR (856–1449 meters) significantly increased injury risk by 73% (RR = 1.73, $p = 0.029$) in elite youth soccer players. Malone et al., (2017) also indicated that male professional soccer players with medium acute S-RPE (1500 to 2120 AU) had higher injury risk (OR = 1.95, $p = 0.006$). In this respect, it was anticipated that very high workload accumulation would increase injury risk. The injured women who had very low workloads might be in too poor a physical condition to play. Both of these women had injuries in the beginning of the season and one did not play in games during the season. Their physical readiness might decline because they lost training time and their overall workload was too low to maintain proper physical conditioning.

At this time, there is no consensus about how very low workload accumulation may affect injury risk. Most previous studies, indicate that very low acute and chronic workload accumulations would not be a risk factor to sustaining an injury. In fact, Bowen et al., (2017) found that low 1-week TD (0 to 8812 meters) accumulation actually reduced injury risk by 75% (RR = 0.25, $p = 0.018$). Also, they reported that acute low HSR (0 to 756 meters) decreased injury risk by 70% (RR = 0.30, $p = 0.004$). Malone et al., (2016) reported that an AC ratio of S-RPE ranging from 1.0 to 1.25 represented the lowest injury risk in professional soccer players. However, a study by Harrison and Johnston (2017) revealed that in the Australian Football League players, those with the lowest workload accumulation (1,250 AU per a week) had the highest injury rate. Bourdon et al., (2017) recently stated that with regard to injury, there is an AC ratio "sweet spot" that ranges from about 0.8 to 1.3. In the current study, two players who were injured had an AC ratio below 0.8 which is at the level when injury increases. In fact, those with low workloads are most likely less physiologically fit. Those who train at AC ratios below 1.0, would most likely not receive enough physiological overload to achieve appropriate training adaptation. Thus, players with a low AC ratio are at risk for injury. Bottom line is that lack of fitness may increase injury risk.

It is not possible to identify a single predictor or threshold value for injury in athletes. Every athlete has a different capacity to endure workload without injury. In fact, there are several workload variables that may influence injury in sports. Past research has revealed that 1-week and 4-week Avg-Spd (Ehrmann et al., 2016), 4-week TD (Bowen et al., 2017), 1-week HSR (Bowen et al., 2017; Malone et al., 2017) and 1-week S-RPE (Malone et al., 2017; Rogalski et al., 2016) were the potential variables important for prevention of injury in elite athletes. Malone, Roe, Doran, Gabbett, and Collins (2017) indicated that the elite Gaelic Football players with a poor score on a 1 kilometer running test had higher risk of injury than those with the high score (OR = 1.50 – 2.50, *p* = .009 – 0.11).

In summary, this study supports the assertion that workload influences injury, however injury occurred at both extremes: very high and very low workload groups. The findings of this study indicate that exposure to high workloads do not universally cause injury. In fact, the results from this study support that injury prevention using micro-technology may be best conducted on an individual level rather than generalizing threshold values for all athletes.

One of the strengths of this study is that it is the first study to examine the correlation between internal and external load in female college soccer players and to identify differences in internal and external load variables in non-injured and injured players. Also, this study would re-introduce a potential of HR variables for injury prevention. Lastly, the other strong point of this research is that both accumulating training too much and too less my cause soft-tissue injuries on lower limbs in female soccer players.

There were four main limitations in this study. First, this study only looked at responses from one team of 25 female college soccer players. Thus these data are not particularly generalizable to other women's sports teams. Second, position differences were not considered (Salvo et al., 2010). Different positions need different running patterns, so these differences could affect the results in this research. Third, there was no way to alter how max HR and max speed were calculated in the software with regard to setting the parameters for specific indexes such as: H-HR zone and HSR. Fourth, menstrual history or status was not controlled for. Lebrun, McKenzie, Prior, and Taution (1995) indicated that menstrual cycle can have a negative effects on aerobic performance. It is not known how menstrual cycle may have affected the outcomes of this study.

In conclusion, the results from this study indicated that there were significant correlations between internal and external load variables in female college soccer players. Also, the injured group had significantly higher acute average heart rate and acute chronic workload ratio of average speed and volume intensity index than the non-injured group. The results also indicated that the acute to chronic workload ratio of the injured players was either much higher or much lower than the injured mean. The study is important for trainers or coaches with regard to creating appropriate and effective workouts that will maximize performance and minimize injury. Future studies should be undertaken to examine the HR threshold categories which will improve the identification of players who are at risk for injury.

This study has four practical applications for coaches and sport medicine staff. First the data support depending on the resources available, a trainer can choose to use

HR monitors, a S-RPE, or a GPS device interchangeable to monitor training. Second, HR variables may have the best potential to anticipate injury risk in female soccer players. Third, when examining injured players, both very high and very low workloads should be evaluated. Finally, female athletes seem to have similar responses to workload variables in regard to injury as male athletes.

REFERENCES

Alexiou, H., & Coutts, A. J. (2008). A comparison of methods used for quantifying internal training load in women soccer players. International Journal of Sports Physiology and Performance, 3(3), 320-330.

Arnason, A., Sigurdsson, S. B., Gudmundsson, A., Holme, I., Engebretsen, L., & Bahr, R. (2004). Physical fitness, injuries, and team performance in soccer. Medicine and Science in Sports and Exercise, 36(2), 278-285. doi:10.1249/01.MSS.0000113478.92945.CA [doi]

Banister, E. W. (1991). Modeling elite athletic performance. In J. Duncan MacDougall, H. A. Wenger, & H. J. Green (Eds.), Physiological testing of the high-performance athlete (2nd ed., pp. 403-424). Champaign, IL: Human Kinetics.

Bourdon, P. C., Cardinale, M., Murray, A., Gastin, P., Kellmann, M., Varley, M. C., . . . Cable, N. T. (2017). Monitoring athlete training loads: Consensus statement. International Journal of Sports Physiology and Performance, 12(Suppl 2), S2161-S2170. doi:10.1123/IJSPP.2017-0208 [doi]

Bowen, L., Gross, A. S., Gimpel, M., & Li, F. X. (2017). Accumulated workloads and the acute:Chronic workload ratio relate to injury risk in elite youth football players. British Journal of Sports Medicine, 51(5), 452-459. doi:10.1136/bjsports-2015-095820 [doi]

Brooks, J. H., Fuller, C. W., Kemp, S. P., & Reddin, D. B. (2005). Epidemiology of injuries in english professional rugby union: Part 2 training injuries. British Journal of Sports Medicine, 39(10), 767-775. doi:39/10/767 [pii]

Brooks, J. H., Fuller, C. W., Kemp, S. P., & Reddin, D. B. (2008). An assessment of training volume in professional rugby union and its impact on the incidence, severity, and nature of match and training injuries. Journal of Sports Sciences, 26(8), 863-873. doi:10.1080/02640410701832209 [doi]

Carey, D. L., Blanch, P., Ong, K. L., Crossley, K. M., Crow, J., & Morris, M. E. (2017). Training loads and injury risk in australian football-differing acute: Chronic workload ratios influence match injury risk. British Journal of Sports Medicine, 51(16), 1215-1220. doi:10.1136/bjsports-2016-096309 [doi]

Chmura, P., Andrzejewski, M., Konefal, M., Mroczek, D., Rokita, A., & Chmura, J. (2017). Analysis of motor activities of professional soccer players during the 2014 world cup in brazil. Journal of Human Kinetics, 56, 187-195. doi:10.1515/hukin-2017-0036 [doi]

Colby, M. J., Dawson, B., Heasman, J., Rogalski, B., & Gabbett, T. J. (2014). Accelerometer and GPS-derived running loads and injury risk in elite australian footballers. Journal of Strength and Conditioning Research, 28(8), 2244-2252. doi:10.1519/JSC.0000000000000362 [doi]

Cummins, C., Orr, R., O'Connor, H., & West, C. (2013). Global positioning systems (GPS) and microtechnology sensors in team sports: A systematic review. Sports Medicine (Auckland, N.Z.), 43(10), 1025-1042. doi:10.1007/s40279-013-0069-2 [doi]

Di Salvo, V., Baron, R., Gonzalez-Haro, C., Gormasz, C., Pigozzi, F., & Bachl, N. (2010). Sprinting analysis of elite soccer players during european champions league and UEFA cup matches. Journal of Sports Sciences, 28(14), 1489-1494. doi:10.1080/02640414.2010.521166 [doi]

Di Salvo, V., Gregson, W., Atkinson, G., Tordoff, P., & Drust, B. (2009). Analysis of high intensity activity in premier league soccer. International Journal of Sports Medicine, 30(3), 205-212. doi:10.1055/s-0028-1105950 [doi]

Ehrmann, F. E., Duncan, C. S., Sindhusake, D., Franzsen, W. N., & Greene, D. A. (2016). GPS and injury prevention in professional soccer. Journal of Strength and Conditioning Research, 30(2), 360-367. doi:10.1519/JSC.0000000000001093 [doi]

Foster, C., Hector, L. L., Welsh, R., Schrager, M., Green, M. A., & Snyder, A. C. (1995). Effects of specific versus cross-training on running performance. European Journal of Applied Physiology and Occupational Physiology, 70(4), 367-372.

Fulstone, D., Chandran, A., Barron, M., & DiPietro, L. (2016). Continued sex-differences in the rate and severity of knee injuries among collegiate soccer players: The NCAA injury surveillance system, 2004-2009. International Journal of Sports Medicine, 37(14), 1150-1153. doi:10.1055/s-0042-112590 [doi]

Gabbett, T. J. (2015). Use of relative speed zones increases the high-speed running performed in team sport match play. Journal of Strength and Conditioning Research, 29(12), 3353-3359. doi:10.1519/JSC.0000000000001016 [doi]

Gabbett, T. J. (2016). The training-injury prevention paradox: Should athletes be training smarter and harder? British Journal of Sports Medicine, 50(5), 273-280. doi:10.1136/bjsports-2015-095788 [doi]

Gabbett, T. J., & Ullah, S. (2012). Relationship between running loads and soft-tissue injury in elite team sport athletes. Journal of Strength and Conditioning Research, 26(4), 953-960. doi:10.1519/JSC.0b013e3182302023 [doi]

Halson, S. L. (2014). Monitoring training load to understand fatigue in athletes. Sports Medicine (Auckland, N.Z.), 44 Suppl 2, S139-47. doi:10.1007/s40279-014-0253-z [doi]

Harrison, P. W., & Johnston, R. D. (2017). Relationship between training load, fitness, and injury over an australian rules football preseason. Journal of Strength and Conditioning Research, 31(10), 2686-2693. doi:10.1519/JSC.0000000000001829 [doi]

Hewitt, A., Norton, K., & Lyons, K. (2014). Movement profiles of elite women soccer players during international matches and the effect of opposition's team ranking. Journal of Sports Sciences, 32(20), 1874-1880. doi:10.1080/02640414.2014.898854 [doi]

Hulin, B. T., Gabbett, T. J., Lawson, D. W., Caputi, P., & Sampson, J. A. (2016). The acute:Chronic workload ratio predicts injury: High chronic workload may decrease injury risk in elite rugby league players. British Journal of Sports Medicine, 50(4), 231-236. doi:10.1136/bjsports-2015-094817 [doi]

Jones, M. R., West, D. J., Crewther, B. T., Cook, C. J., & Kilduff, L. P. (2015). Quantifying positional and temporal movement patterns in professional rugby union using global positioning system. European Journal of Sport Science, 15(6), 488-496. doi:10.1080/17461391.2015.1010106 [doi]

Krustrup, P., Mohr, M., Ellingsgaard, H., & Bangsbo, J. (2005). Physical demands during an elite female soccer game: Importance of training status. Medicine and Science in Sports and Exercise, 37(7), 1242-1248. doi:00005768-200507000-00024 [pii]

Larsson, P. (2003). Global positioning system and sport-specific testing. Sports Medicine (Auckland, N.Z.), 33(15), 1093-1101. doi:33151 [pii]

Lebrun, C. M., McKenzie, D. C., Prior, J. C., & Taunton, J. E. (1995). Effects of menstrual cycle phase on athletic performance. Medicine and Science in Sports and Exercise, 27(3), 437-444.

Malone, S., Doran, D., Akubat, I., & Collins, K. (2016). The integration of internal and external training load metrics in hurling. Journal of Human Kinetics, 53, 211-221. doi:10.1515/hukin-2016-0024 [doi]

Malone, S., Owen, A., Mendes, B., Hughes, B., Collins, K., & Gabbett, T. J. (2018). High-speed running and sprinting as an injury risk factor in soccer: Can well-developed physical qualities reduce the risk? Journal of Science and Medicine in Sport, 21(3), 257-262. doi:S1440-2440(17)30442-5 [pii]

Malone, S., Owen, A., Newton, M., Mendes, B., Collins, K. D., & Gabbett, T. J. (2017). The acute:Chonic workload ratio in relation to injury risk in professional soccer. Journal of Science and Medicine in Sport, 20(6), 561-565. doi:S1440-2440(16)30230-4 [pii]

Malone, S., Roe, M., Doran, D. A., Gabbett, T. J., & Collins, K. D. (2017). Protection against spikes in workload with aerobic fitness and playing experience: The role of the acute:Chronic workload ratio on injury risk in elite gaelic football. International Journal of Sports Physiology and Performance, 12(3), 393-401. doi:10.1123/ijspp.2016-0090 [doi]

Manzi, V., Bovenzi, A., Franco Impellizzeri, M., Carminati, I., & Castagna, C. (2013). Individual training-load and aerobic-fitness variables in premiership soccer players during the precompetitive season. Journal of Strength and Conditioning Research, 27(3), 631-636. doi:10.1519/JSC.0b013e31825dbd81 [doi]

Manzi, V., Iellamo, F., Impellizzeri, F., D'Ottavio, S., & Castagna, C. (2009). Relation between individualized training impulses and performance in distance runners. Medicine and Science in Sports and Exercise, 41(11), 2090-2096. doi:10.1249/MSS.0b013e3181a6a959 [doi]

Mufty, S., Bollars, P., Vanlommel, L., Van Crombrugge, K., Corten, K., & Bellemans, J. (2015). Injuries in male versus female soccer players: Epidemiology of a nationwide study. Acta Orthopaedica Belgica, 81(2), 289-295.

Mujika, I., Chatard, J. C., Busso, T., Geyssant, A., Barale, F., & Lacoste, L. (1995). Effects of training on performance in competitive swimming. Canadian Journal of Applied Physiology = Revue Canadienne De Physiologie Appliquee, 20(4), 395-406.

Murray, N. B., Gabbett, T. J., Townshend, A. D., & Blanch, P. (2017). Calculating acute:Chronic workload ratios using exponentially weighted moving averages provides a more sensitive indicator of injury likelihood than rolling averages. British Journal of Sports Medicine, 51(9), 749-754. doi:10.1136/bjsports-2016-097152 [doi]

Nikolaidis, P. T. (2015). Maximal heart rate in soccer players: Measured versus age-predicted. Biomedical Journal, 38(1), 84-89. doi:10.4103/2319-4170.131397 [doi]

Owen, A. L., Forsyth, J. J., Wong del, P., Dellal, A., Connelly, S. P., & Chamari, K. (2015). Heart rate-based training intensity and its impact on injury incidence among elite-level professional soccer players. Journal of Strength and Conditioning Research, 29(6), 1705-1712. doi:10.1519/JSC.0000000000000810 [doi]

Paulson, T. A., Mason, B., Rhodes, J., & Goosey-Tolfrey, V. L. (2015). Individualized internal and external training load relationships in elite wheelchair rugby players. Frontiers in Physiology, 6, 388. doi:10.3389/fphys.2015.00388 [doi]

Rampinini, E., Alberti, G., Fiorenza, M., Riggio, M., Sassi, R., Borges, T. O., & Coutts, A. J. (2015). Accuracy of GPS devices for measuring high-intensity running in field-based team sports. International Journal of Sports Medicine, 36(1), 49-53. doi:10.1055/s-0034-1385866 [doi]

Rietjens, G. J., Kuipers, H., Adam, J. J., Saris, W. H., van Breda, E., van Hamont, D., & Keizer, H. A. (2005). Physiological, biochemical and psychological markers of strenuous training-induced fatigue. International Journal of Sports Medicine, 26(1), 16-26. doi:10.1055/s-2004-817914 [doi]

Ristolainen, L., Heinonen, A., Waller, B., Kujala, U. M., & Kettunen, J. A. (2009). Gender differences in sport injury risk and types of inju-ries: A retrospective twelve-month study on cross-country skiers, swimmers, long-distance runners and soccer players. Journal of Sports Science & Medicine, 8(3), 443-451.

Rogalski, B., Dawson, B., Heasman, J., & Gabbett, T. J. (2013). Training and game loads and injury risk in elite australian footballers. Journal of Science and Medicine in Sport, 16(6), 499-503. doi:10.1016/j.jsams.2012.12.004 [doi]

Scanlan, A. T., Wen, N., Tucker, P. S., & Dalbo, V. J. (2014). The relationships between internal and external training load models during basketball training. Journal of Strength and Conditioning Research, 28(9), 2397-2405. doi:10.1519/JSC.0000000000000458 [doi]

Scott, B. R., Lockie, R. G., Knight, T. J., Clark, A. C., & Janse de Jonge, X. A. (2013). A comparison of methods to quantify the in-season training load of professional soccer players. International Journal of Sports Physiology and Performance, 8(2), 195-202.

Scott, M. T., Scott, T. J., & Kelly, V. G. (2016). The validity and reliability of global positioning systems in team sport: A brief review. Journal of Strength and Conditioning Research, 30(5), 1470-1490. doi:10.1519/JSC.0000000000001221 [doi]

Stubbe, J. H., van Beijsterveldt, A. M., van der Knaap, S., Stege, J., Verhagen, E. A., van Mechelen, W., & Backx, F. J. (2015). Injuries in professional male soccer players in the netherlands: A prospective cohort study. Journal of Athletic Training, 50(2), 211-216. doi:10.4085/1062-6050-49.3.64 [doi]

Vanrenterghem, J., Nedergaard, N. J., Robinson, M. A., & Drust, B. (2017). Training load monitoring in team sports: A novel framework separating physiological and biomechanical load-adaptation pathways. Sports Medicine (Auckland, N.Z.), 47(11), 2135-2142. doi:10.1007/s40279-017-0714-2 [doi]

Vickery, W., Dascombe, B., & Duffield, R. (2017). The association between internal and external measures of training load in batsmen and medium-fast bowlers during net-based cricket training. International Journal of Sports Physiology and Performance, 12(2), 247-253. doi:10.1123/ijspp.2015-0770 [doi]

Vickery, W. M., Dascombe, B. J., Baker, J. D., Higham, D. G., Spratford, W. A., & Duffield, R. (2014). Accuracy and reliability of GPS devices for measurement of sports-specific movement patterns related to cricket, tennis, and field-based team sports. Journal of Strength and Conditioning Research, 28(6), 1697-1705. doi:10.1519/JSC.0000000000000285 [doi]

Volpi, P., & Taioli, E. (2012). The health profile of professional soccer players: Future opportunities for injury prevention. Journal of Strength and Conditioning Research, 26(12), 3473-3479. doi:10.1519/JSC.0b013e31824e195f [doi]

Walden, M., Hagglund, M., Werner, J., & Ekstrand, J. (2011). The epidemiology of anterior cruciate ligament injury in football (soccer): A review of the literature from a gender-related perspective. Knee Surgery, Sports Traumatology, Arthroscopy : Official Journal of the ESSKA, 19(1), 3-10. doi:10.1007/s00167-010-1172-7 [doi]

Wallace, L. K., Slattery, K. M., & Coutts, A. J. (2009). The ecological validity and application of the session-RPE method for quantifying training loads in swimming. Journal of Strength and Conditioning Research, 23(1), 33-38. doi:10.1519/JSC.0b013e3181874512 [doi]

Wong, P., & Hong, Y. (2005). Soccer injury in the lower extremities. British Journal of Sports Medicine, 39(8), 473-482. doi:39/8/473 [pii]

APPENDIX A

SUN DEVIL ATHLETICS RESEARCH AND TECHNOLOGY APPROVAL FORM

Arizona State University Sun Devil Athletics (SDA) requires that all investigative studies that wish to involve student-athletes be approved by the Research and Technology Committee (SDA-RTC) in addition to any relevant Institution Review Board. SDA-RTC is a multi-disciplinary committee that seeks to further enhance the student-athlete care, development and experience by participating in research that will improve evidence based practices. SDA is greatly interested in research that will provide a benefit to student-athletes as well as societal benefits and desires to establish collaborative partnerships with the various academic departments of ASU as well as any external institution that have similar goals. For most projects that anticipate publication, SDA-RTC may request or require co-authorship. Thank you for your interest in collaborating with SDA. Please provide the information requested below.

Name of the project:

Name, Institution, Department and Contact Information of Primary Investigator:

Objective of the study/project:

Time Line/Frame:

Methodology of the study/project:

Benefits of the project:

Expected time commitment of ASU staff or athlete:

Expected ASU resource requirement:

Athlete compensation (as allowed by NCAA regulations):

ASU or Institutional IRB approval/date:

Additional training or restrictions (IE HIPAA, FERPA, OSHA):

Publication expectations/ ownership and protection of data:

Co-authorship opportunities:

Please attach any relevant documentation: