

**The acute:chronic workload ratio and injury occurrence
among South African PSL soccer players.**

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Sport Science. Faculty of Education at Stellenbosch University.*



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ABSTRACT

Purpose: Soft-tissue, non-contact injuries (STNCI) are the most prevalent injuries in professional soccer. Considerable research has focussed on injury prevention and training load (TL) monitoring, however, the multifactorial nature of injury occurrence is often neglected. As such, both internal and external TL were examined in this study with the intention of enhancing current understanding of the mechanisms behind STNCI. The acute:chronic workload ratio (ACWR) was used to model the internally and externally derived workloads, providing a dynamic representation of preparedness and subsequent injury risk. This study aimed to identify and describe the association of both internal and external workload variables and injury risk in the subsequent week using the ACWR among professional South African Premier Soccer League (PSL) players.

Article one: Article one examined the association between internally-derived TL (session rating of perceived exertion [sRPE]) and injury risk in the subsequent week utilising the ACWR and 1-, 2-, 3- and 4-weekly cumulative TL. TL data was collected from 41 professional male soccer players over one and a half seasons. In total, 85 STNCIs were recorded. Only the ACWR was significantly associated ($p < 0.05$) with injury in the subsequent week. The workload-injury relationship was sigmoidal (s-shaped) in nature. An increased injury risk in the subsequent week was found at moderate-low (0.77-0.89; OR: 1.67, 95% CI: 1.23-2.27) and high (> 1.14 ; OR: 1.26, 95% CI: 1.06-1.50) ACWR zones, while a low (< 0.77 ; OR: 0.29, 95% CI: 0.14-0.61) ACWR zone exhibited a most likely beneficial effect compared to a moderate-high ACWR zone.

Article two: Article two investigated the association between externally-derived (global positioning systems [GPS] and accelerometer-derived mechanical load indicators) and injury likelihood in the subsequent week utilising the ACWR. Total distance (TD), high intensity speed (HIS), high intensity acceleration (HIA) and high intensity deceleration (HID) data, was collected from 37 professional male soccer players over one and a half seasons. The workload-injury relationship was sigmoidal (s-shaped) and quadratic (u-shaped) in nature. Increased injury likelihood for the subsequent week was identified at high {(TD; > 1.30 , OR: 1.78, 95% CI: 0.72-4.38)(HIS; > 1.41 , OR: 1.74, 95% CI: 0.80-3.77)(HIA; > 1.41 , OR: 1.80, 95% CI 1.00-3.24)}, moderate-high (HID; > 1.37 , OR: 0.80, 95% CI 0.39-

2.76) and low (HIA; <0.77, OR: 1.29, 95% CI 1.00-1,66) ACWR zones, when compared to a moderate ACWR (~0.91 to ~1.20) zone.

Conclusion: The workload-injury relationship was sigmoidal in nature and players exposed to acute de-loads and spikes in TL experienced an increased risk of subsequent injury. A moderate ACWR of between ~0.91 to ~1.20 represents the most realistic, optimal TL index to maintain or improve fitness and/or preparedness, while limiting injury likelihood. The similar sigmoidal nature of injury risk between internally and externally derived TL implies that sRPE may be a useful alternative to costly GPS systems in the world of injury prevention for soccer players - which is of significant importance in a South African context.

Key words: Acute:chronic workload ratio, session rating of perceived exertion, global positioning systems, training load monitoring, team sport.

OPSOMMING

Doel: Sagte weefsel, nie-kontak beserings (SWNKB) is die mees heersende beserings wat in professionele sokker voorkom. Aansienlik baie navorsing het op die voorkoming van beserings en inoefeningslading (IL) monitering gefokus, maar die multifaktoriese aard in die voorkoms van beserings word baie keer afgeskeep. As sulks is beide interne en eksterne IL in hierdie studie nagevors met die voorneme om die huidige kennis van die meganismes agter SWNKB uit te brei. Die akute:kroniese werkklading ratio (AKWR) is gebruik om die interne en eksterne afgeleide werkkladings te ontwerp en om 'n dinamiese voorstelling van voorbereiding en daaropvolgende beseringsrisiko te voorsien. Die huidige studie het gepoog om die assosiasie van beide interne en eksterne werkklading veranderlikes en die risiko van beserings te identifiseer en te bespreek in die daaropvolgende week deur die AKWR onder professionele Suid-Afrikaanse Premier Sokkerliga (PSL) spelers te gebruik.

Artikel een: Artikel een het die assosiasie tussen intern-afgeleide IL (sessie gradering van waargenome inspanning [sGWI]) en die risiko van beserings ondersoek deur van die AKWR en 1-, 2-, 3- en 4-weeklikse kumulatiewe IL gebruik te maak. IL data is by 41 professionele manlike sokkerspelers oor 'n periode van een en 'n halwe seisoen ingesamel. In totaal is 85 SWNKB's aangeteken. Slegs die AKWR was betekenisvol ($p < 0.05$) geassosieer met beserings in die daaropvolgende week. Die werkklading beserings verhouding was sigmoïdaal (s-vorming) van aard. 'n Verhoogde beseringsrisiko in die daaropvolgende week was matig-laag (0.77-0.89; OR: 1.67, 95% CI: 1.23-2.27) en hoë (> 1.14 ; OR: 1.26, 95% CI: 1.06- 1.50) AKWR sones, terwyl 'n lae (< 0.77 ; OR: 0.29, 95% CI: 0.14-0.61) AKWR sone die mees waarskynlike voordelige effek in vergelyking met 'n matig hoë AKWR sone getoon het.

Artikel twee: Artikel twee het die assosiasie tussen ekstern afgeleide (globale posisionering sisteme [GPS] en versnellingsmeter afgeleide meganiese lading aanwysers) en die waarskynlikheid van beserings in die daaropvolgende week ondersoek deur van die AKWR gebruik te maak. Totale afstand (TA), hoë intensiteit spoed (HIS), hoë intensiteit versnelling (HIV) en hoë intensiteit spoedvermindering (HISv) data is by 37 professionele manlike sokkerspelers oor 'n periode van een en 'n halwe seisoen versamel. Die werkklading besering

verhouding was sigmoïdaal (s-vormig) en kwadraties (u-vormig) van aard. Die waarskynlikheid van 'n verhoogde moontlikheid vir beserings in die daaropvolgende week is as hoog geïdentifiseer {(TA; >1.30, OR: 1.78, 95% CI: 0.72-4.38)(HIS; >1.41, OR: 1.74, 95% CI: 0.80-3.77)(HIV; >1.41, OR: 1.80, 95% CI 1.00-3.24)}, matig-hoog (HISv; >1.37, OR: 0.80, 95% CI 0.39-2.76) en laag (HIV; <0.77, OR: 1.29, 95% CI 1.00-1,66) AKWR sones, wanneer dit met 'n matige AKWR (~0.91 to ~1.20) sone vergelyk.

Gevolgtrekking: Die werkklading beseringsverhouding was sigmoïdaal van aard en spelers wat aan akute verminderde werkkladings en skielike toenames in IL blootgestel was, het 'n verhoogde risiko van daaropvolgende beserings ervaar. 'n Matige AKWR van tussen ~0.91 tot ~1.20 verteenwoordig die mees realistiese en optimale IL indeks om fiksheid en/of voorbereidheid te handhaaf of te verbeter terwyl die waarskynlikheid van beserings verminder. Die soortgelyke sigmoïdale aard van beseringsrisiko tussen intern- en ekstern-afgeleide IL impliseer dat sGWI 'n nuttige alternatief is vir duur GPS sisteme in die wêreld van beseringsvoorkoming vir sokkerspelers - wat van betekenisvolle belang in 'n Suid-Afrikaanse konteks is.

Sleutelwoorde: akute:kroniese werkklading ratio, sessie gradering van waargenome inspanning, globale posisionering sisteme, inoefeningslading, spansport.

CONTENTS

Chapter One: Problem Statement and Aims	1
1.1 Introduction	1
1.2 Aims of the study	7
1.2.1 Specific aims	7
1.2.2 Objectives	7
1.3 Motivation and potential benefits	8
Chapter Two: Training Load Monitoring	9
2.1 Current state of training load monitoring	9
2.2 Internal training load monitoring	11
2.2.1 Psychological measures	11
2.2.2 Physiological measures	16
2.3 External training load monitoring	25
2.3.1 Global positioning systems (GPS)	25
2.4 Summary: External and internal training load monitoring	33
2.5 The acute:chronic workload ratio (ACWR)	34
2.5.1 What is the ACWR?	34
2.5.2 Quantifying the ACWR	36
2.5.3 What can be used to calculate the ACWR?	44
2.5.4 The ACWR and research findings	45
2.5.5 Potential limitations of the ACWR	51
2.6 Considerations for current research	53
Chapter Three: Article One	55
Chapter Four: Article Two	64
Chapter Five: Conclusions and Recommendations	74
5.1 Literature overview	74
5.2 Conclusion	75
5.2.1 Objective one	75

5.2.2 Objective two	75
5.2.3 Objective three	76
5.3 Implications for practitioners	77
5.3.1 Session-RPE as a useful alternative	77
5.3.2 The sigmoidal workload injury relationship	78
5.3.3 Optimal workload range	79
5.3.4 Summary	79
5.4 Implications for future research	79
5.4.1 The ACWR model	80
5.4.2 Daily ACWR vs. weekly ACWR	80
5.4.3 Multivariate vs. Univariate analysis	80
5.4.4 Individual vs. Team analysis	80
5.5 Study limitations	81
References	82
Appendices	104
Appendix A: Letter of permission	104
Appendix B: REC approval letter	105
Appendix C: REC cover letter	107
Appendix D: Information sheet (English)	108
Appendix E: Information sheet (Afrikaans)	111
Appendix F: Informed consent form (English)	114
Appendix G: Informed consent form (Afrikaans)	118

LIST OF FIGURES

	p.
Chapter Two: Training Load Monitoring	
Figure 2. 1 Example of the variation observed between HB.....	21
Figure 2. 2 The dose-response systems model.....	41
Figure 2. 3 The relationship between RA ACWR and EWMA ACWR	42
Figure 2. 4 The U-Shape relationship between ACWR and injury risk	46
Chapter Three: Article One	
Fig. 1. The likelihood of injury (%)	61
Fig. 2a-b. MBI ACWR injury risk.....	62
Chapter Four: Article Two	
Fig. 1. The likelihood of injury (%).....	71
Fig. 2. MBI ACWR injury likelihood.....	72
Chapter Five: Conclusion and Recommendations	
Figure 5. 1 The sigmoidal workload-injury relationship.....	78

LIST OF TABLES

p.

Chapter Two: Training Load Monitoring

Table 2. 1 Summary of sRPE validity and reliability	13
Table 2. 2 ACWR and injury risk.	47
Table 2. 3 ACWR, change in workload, and injury risk.....	50

Chapter Three: Article One

Table 1 GEE model effects.....	61
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Chapter Four: Article Two

Table 1 Definition of GPS variables.....	69
Table 2 Classification of non-contact injuries.....	70

ABBREVIATIONS

ACWR	:	Acute:chronic workload ratio
AF	:	Australian football
ANS	:	Autonomic nervous system
HB	:	Heart beat
CI	:	Confidence intervals
CK	:	Creatine kinase
CMJ	:	Countermovement jump
ECG	:	Electrocardiogram
EWMA	:	Exponentially weighted moving average model
FIFA	:	The Federation Internationale de Football Association
GEE	:	Generalised estimation equation
GPS	:	Global positioning systems
HFP	:	High-frequency power
HIA	:	High intensity acceleration
HID	:	High intensity deceleration
HIS	:	High intensity speed
HR	:	Heart rate
HRV	:	Heart rate variability
HSR	:	High speed running
Hz	:	Hertz
La	:	Lactate
[La]	:	Lactate concentration
MBI	:	Magnitude based inference
NF	:	Neuromuscular function
OBLA	:	Onset of blood lactate accumulation
OR	:	Odds ratios
PNS	:	Parasympathetic nervous system
POMS	:	Profile of mood states
PSL	:	Premier Soccer League
RA	:	Rolling average model
RESTQ	:	Recovery-stress questionnaire for athletes

RMSSD	:	Root-mean square difference of successive normal R-R
RPE	:	Rating of perceived exertion
SNS	:	Sympathetic nervous system
sRPE	:	Session rating of perceived exertion
TD	:	Total distance
TL	:	Training load
TRIMP	:	Training impulse
VT	:	Ventilatory threshold

Chapter One

PROBLEM STATEMENT AND AIMS

1.1 INTRODUCTION

Soccer is a sport with a high physiological demand that requires diverse athletic capability, from aerobic endurance to explosive power and repeated sprint ability (Stebbing, 2015). The nature of the sport, both in training and during matches, is intermittent and intense. Both the oxygen dependent and oxygen independent energy systems of soccer players are taxed, especially at the higher echelons of the game (Bangsbo, 2014). Mohr *et al.* (2003) observed that elite soccer players perform 150-250 brief intense actions (e.g., accelerations, decelerations, turns and jumps) during a game, suggesting that the rate of non-oxidative energy turnover is high. It is for this reason that players need to be well conditioned in order to cope with the high metabolic demand of the sport.

Elite soccer players typically cover a distance of 10-13 km per match (Krustrup *et al.*, 2005; Bangsbo *et al.*, 2006; Bangsbo, 2014). According to Bangsbo *et al.* (2006) players perform low-intensity activities for more than 70% of the game, however, their heart rates and body temperatures suggest that the average oxygen uptake is around 70% of the player's $\dot{V}O_{2max}$. This high physical and metabolic load is as a result of not only straight line running and intermittent activity, but the accumulation of high energy activities such as short accelerations, turns, actions on the ball, tackles and jumps (Bangsbo, 2014). Findings of Reilly (1997) suggest that the summation of this physical activity results in fatigue, both on an acute (short-term) and a chronic (long-term) level.

Fatigue increases during a match due to continued physical exertion and there is evidence to suggest that as a result, there is a decrement in physical performance. In particular, some studies have shown that the proportion of high intensity running and sprinting decreases between the first and second half (Mohr *et al.*, 2003; Krustrup *et al.*, 2005). This decline in physical work has been linked to match related physical fatigue (Mohr *et al.*, 2003). As a result of this physical

fatigue, soccer players' technical skills have also been shown to decrease (Rampinini *et al.*, 2009).

In conjunction with a player's decline in physical performance and technical skill, there is an increase in the risk of injury. According to Small *et al.* (2009), movement mimicking the physiological and mechanical demands of soccer match-play resulted in a time-dependent variation in sprinting kinematics. These 'acute' fatigue-induced alterations resulted in impaired sprinting performance at the ends of each half and increased strain on the hamstrings, subsequently increasing the risk of injury. In a review by Wong and Hong (2005) on soccer injuries in the lower extremities, the majority of the studies reported more injuries during competition than during training. However, training injuries were prevalent in all of the reviewed articles and in the study by Hawkins and Fuller (1998), training injury occurrence was higher than competition injury occurrence.

In a study, that consisted of 51 elite soccer teams (2299 players in total), there were 2908 muscle injuries over the course of a full competitive season (Ekstrand *et al.*, 2011). The study indicated that on average, 0.6 muscle injuries were sustained per player. Therefore, a squad of 25 players can expect approximately 15 muscle injuries per season, which constitutes 31% of all injury occurrence and results in 27% of the total injury absence (Ekstrand *et al.*, 2011). Findings of Ekstrand *et al.* (2011), suggest that muscle injuries are a substantial problem for professional soccer players and their clubs, because these muscle injuries constitute one-third of all time-loss injuries within a professional club setting.

Large amounts of money are invested by clubs into new players during each transfer window; both as once off transfer fees and weekly wages, with some transfers exceeding the €100 million mark. It is, therefore, safe to surmise that injuries and the time needed for players to recuperate potentially represent a large financial loss to a club, considering the injured players are no longer contributing directly to match-play and helping the team achieve results. Therefore, the need to reduce injury occurrence is vital and has led to substantial investment into research and deployment of additional staff members to prepare

players more effectively, implement injury prevention procedures and monitor training load (TL).

Research has shown that strategies designed to prevent sports injuries can be effective (Parkkari *et al.*, 2001; Olsen, 2004). Medical and sport science practitioners have implemented various injury prevention procedures and protocols. A popular injury prevention protocol, the FIFA 11+ warm-up has been shown to significantly reduce injury incidence (Silvers-Granelli *et al.*, 2015). The protocol reduced injury rates among collegiate soccer players, by 46.1% and decrease time lost to injury by 28.6% (Silvers-Granelli *et al.*, 2015). Other studies have focused on conditioning and periodisation in order to best prepare athletes for the high physical and metabolic loads experienced during training and match-play (Kraemer *et al.*, 2000; Hewett *et al.*, 2005; Durall *et al.*, 2009).

With regard to conditioning and injury prevention, different methods of resistance training seems to be effective in preparing an athlete for the demands imposed by their specific sport and could prevent injury. For example, Durall *et al.* (2009) noted the occurrence of back pain was prevented by training muscles of the 'core' in collegiate gymnasts during the pre-season. Interestingly, similar exercises (as Durall *et al.*, 2009) prevented knee injuries in female intercollegiate basketball players (Hewett *et al.*, 2005). Even though these prevention programmes were successful, the need for adequate, well-planned periodisation was highlighted. According to Kraemer *et al.* (2000), in a study investigating the effect of periodised resistance training on performance and physiological adaptations, it was reported that the training group that received periodised resistance training produced superior strength and power adaptations compared to the control and non-periodised training groups. The same group also experienced continued improvements beyond the initial four months of training in strength, power and injury prevention. The need for periodisation was further emphasised, this time in terms of injury prevention, by Mallo and Dellal (2012). They identified a difference in injury risk patterns related to the period of the season and, therefore, injury prevention strategies should ideally be introduced during the pre-season. Furthermore, training workloads should be controlled to avoid an increase in injury risk.

The prescription and monitoring of TL in team sports are commonly utilised in an attempt to reduce injury risk. The physiological stress caused by the high metabolic requirement of performing soccer actions is commonly referred to as the internal load (Halson, 2014). The internal load is incurred as a result of the amount of work completed (external load), frequently recorded as total distance covered or the total number of minutes completed during training and match play (Halson, 2014). A commonly utilised method of determining the internal load of an athlete is the session rating of perceived exertion (sRPE) (Foster *et al.*, 2001). The internal TL is calculated by multiplying an athlete's rating of perceived exertion (RPE) following an exercise bout, by the duration (in minutes) of the bout, usually represented in arbitrary units (AU). RPE has been shown to be to have a strong positive correlation with heart-rate based monitoring methods (Borg & Noble, 1974; Mihevic, 1981). Using sRPE to quantify internal TL has its advantages as it is sensitive to an individual's unique response to the prescribed TL (Impellizzeri *et al.*, 2004). However, it is still important to measure external TL in order to better understand how the prescribed TL affects players on an individual basis (Halson, 2014). A player's internal TL will likely correspond with their fatigue levels and, therefore, potentially predict injury risk. In addition, internal TL may assist in understanding any possible adaptations to load and subsequent readiness to compete (Saw *et al.*, 2015).

The external load of an athlete is defined as the quantity of work completed by an athlete within a training session or match, and is measured independently of his or her internal characteristics (Wallace *et al.*, 2009). An example of external TL in soccer would be the total number of high-intensity accelerations (e.g., 64 accelerations in 60 minutes). While external TL monitoring allows sports medicine practitioners and sport scientists to understand the work completed, as well as the capabilities and capacities of an athlete, internal TL monitoring, or the relative physiological and psychological stress imposed by physical activity, is also critical in order to determine the perceived TL of an individual and any subsequent adaptation (Halson, 2014). Considering both the internal and external load may have merit with respect to the monitoring and the understanding of TL, because a combination of both, could aid in revealing fatigue and thus, preventing subsequent injury. For example, using the external TL mentioned above, the

number of high-intensity accelerations per minute may be calculated, and depending on the fatigue state of a player, this may be achieved with either a high or low sRPE. It is this uncoupling or divergence of internal and external TL that may assist in distinguishing between a fresh and a fatigued player and any subsequent injury risk (Halson, 2014).

While injuries are a common occurrence in competitive soccer, the risk of an athlete sustaining injuries, particularly soft tissue injuries not associated with a contact or collision, can be reduced with TL monitoring (Ekstrand *et al.*, 2011). A study by Gabbett (2004) reported a significant positive correlation ($r = 0.86$) between absolute TL and injury occurrence in rugby league players. This suggests that the harder an athlete trains, the more injuries they will sustain. Similar findings have been reported in studies involving sub-elite junior and senior rugby league players in which high TL in the early phases of the season were associated with higher injury rates. Reductions in TL in the competitive phase of the season resulted in lower training injury rates (Gabbett, 2005a; 2005b). However, these conclusions do not account for the impact on injury risk of the previous weeks or months of training. Similarly, the absolute TL does not account for the acquired fitness and physical condition that have been developed. The improved physical and metabolic conditions of the athlete allow the individual to become more resistant to fatigue as well as improving the ability to dissipate fatigue (Hawley, 2002; Reilly, 2008). A better indicator of the relationship between fitness and the fatigue accumulation in training and subsequent injury risk may be the acute:chronic workload ratio (ACWR) (Hulin *et al.*, 2014).

The ACWR takes into account the TL of the current week's training (acute load) and compares it to the average of the previous four weeks training (chronic load) (Hulin *et al.*, 2014). This method allows sports scientists to better compare and understand the loads that players are accustomed to (fitness) and the load that is currently being prescribed (fatigue). It was reported by Gabbett (2017) that the ACWR is a predictor of non-contact injury risk. The risk of injury was shown to increase when a low chronic load (fitness) is combined with a very high acute load (fatigue). Gabbett (2016a) refers to this phenomenon as a TL spike. In

contrast, when high acute TL (fatigue) is combined with a high chronic TL (fitness), both the risk of injury and the risk of re-injury are decreased.

An ACWR of approximately 1.50 and above, indicative of a large acute load, resulted in a very high risk of injury when compared to a moderate acute load or a high chronic load, which results in an ACWR of between 0.85 and 1.35 (Gabbett, 2016a). This range has been termed the training 'sweet spot'. At this range, athletes showed an increased resistance to injury and the lowest risk of injury (Gabbett, 2016a). These acute and chronic workload relationships were investigated by Bowen *et al.* (2016) who focused on external variables in elite youth soccer players to evaluate injury risk. The study found similar results to studies conducted in cricket, Australian football (AF) and rugby league (Hulin *et al.*, 2014; Murray *et al.*, 2016; Windt *et al.*, 2016). Non-contact injury risk was significantly increased when high acute loads were combined with low chronic loads, but not when combined with a high chronic load. These findings support Gabbett's 'Injury Prevention Paradox' which states that high chronic TL developed via steady progressions can improve players' resistance to injury. While, in contrast spikes in acute TL combined with a low chronic load significantly increased the risk of injury (Gabbett, 2016a).

The high incidence of injury in soccer and the financial implications for clubs have highlighted the importance of injury prevention. It is subsequently important to understand TL and the relationship between TL and injury occurrence. The evidence suggests that the problem is not with the specific format of the training *per se*, but more likely that inappropriate TL is being prescribed. In this regard, Gabbett (2016a) suggests that excessive and rapid increases in TL may be responsible for the majority of non-contact, soft-tissue injury in team sports. However, appropriately planned and periodised physically challenging TL results in the development of physical qualities which in turn protect against injury. It is, therefore, vital to monitor both internal and external TL. This will allow practitioners to explore possible relationships between TL and injury risk and subsequently investigate the load that players are prepared for (by calculating the ACWR). Doing so may assist in the achievement of the long-term reduction of training related injuries and allow for the construction of prediction

models to better guide training and enhance performance.

1.2 AIMS OF THE STUDY

To date, there is limited research that has investigated the relationship between the acute and chronic workloads and the ACWR with regards to injury occurrence among professional soccer players.

1.2.1 Specific aims

The study primarily aims to identify and describe:

- The association of both internal and external workload indicators and injury risk in the subsequent week among professional South African Premier Soccer League (PSL) players.

The secondary aims are to enhance the understanding and accuracy of the aforementioned factors:

- To ascertain which workload conditions either increase or decrease the risk of injury in the subsequent week, and
- To describe and illustrate the nature or shape of the workload-injury relationship to allow for better interpretation of any associations and/or relationships identified.

1.2.2 Objectives

The objectives of the study address the investigation of both internally and externally-derived ACWR and their association with injury risk or injury likelihood in the subsequent week. Therefore, the investigation of both TL components in this study (internal and external) allows the researchers to fulfill three specific objectives:

1. To determine the association between the ACWR and injury risk or injury likelihood in the subsequent week.
2. To analyse and describe the shape of the workload-injury relationship with regards to the ACWR.
3. To identify and assess which ACWR conditions either increase or decrease injury risk or injury likelihood in the subsequent week.

1.3 MOTIVATION AND POTENTIAL BENEFITS

This study will address the limited research that exists surrounding TL monitoring in elite male soccer players, more specifically the ACWR and injury risk. Through this study, in-depth information will be gained that could potentially guide future training prescription and help prevent injuries in elite soccer players. The utilization of both internal and external TL will provide a greater scope in terms of monitoring and help highlight important variables that correlate strongly with injury and assist in the reduction of future injury. Therefore, results will allow sports scientists and sports medicine practitioners to tailor monitoring programmes to better understand an athlete's workload to enhance performance and prevent injury.

Chapter Two

TRAINING LOAD MONITORING

An earlier draft of this literature study, specific to the ACWR section, was made available on the Science for Sport website in November of 2017 (See link below). Science for sport is a website dedicated to sport science, sports medicine, and coaching education and currently receives more than 1.2 million yearly visitors.

To accompany the ACWR review, the author of this study (Ryan White), created a freely downloadable excel spreadsheet that serves as a TL and ACWR monitoring calculator which aims to assist practitioners in interpretation of their TL data. To date the ACWR review and spreadsheet has been read and downloaded more than 100 000 times. This clearly indicates the relevance and interest towards this topic.

Science for Sport link: [<https://www.scienceforsport.com/acutechronic-workload-ratio/>]

2.1 CURRENT STATE OF TRAINING LOAD MONITORING

Sport is evolving continuously and has taken great strides over the past few decades, from games played principally for enjoyment, to a competitive professionalised industry (Hill & Williams, 2010). Athletes participating in elite sports are exposed to increasingly higher TL, saturated competition calendars, and very short periods of rest and recovery (Soligard *et al.*, 2016). In a study by Bengtsson *et al.* (2013a), match congestion was associated with increased injury rates. Further studies have also shown that higher injury rates have a major effect on a team's overall performance and final log standings (Eirale *et al.*, 2012; Bengtsson *et al.*, 2013b). As such, reducing the amount of time lost through injury is extremely important.

Given the importance of player availability in terms of overall team performance, there has been a surge in TL and monitoring research in recent years (Bourdon *et al.*, 2017). This research suggests that poor TL management and prescription

are major risk factors for injury (Soligard *et al.*, 2016). TL-related injuries are, for the most part, preventable, and thus sport science and sports medicine practitioners should address these issues by implementing TL monitoring protocols (Gabbett, 2016a). These TL monitoring protocols need to: address the issues of TL management and prescription to prevent injury, track individual athletes' readiness to train and compete, and most importantly, improve performance.

In order to address the issues of TL management and prescription, it is important to define and understand training and match load. According to Coyle (2000), physical activity, with respect to training and match load, imposes a physiological stress. If exposure to the stress of exercise is consistent, the stressed physiological systems of the body will adapt. The relationship between the physiological stress and adaptation is better known as the dose-response relationship (Lambert & Borresen, 2010). This response can be measured as a change in performance or the adaptation of a physiological system. The dose of training is the physiological stress associated with the TL. It is therefore, imperative to be able to quantify and measure TL so that the dose of training can be progressively and carefully planned to achieve the optimal balance between performance enhancement and injury risk.

In order to measure TL, practitioners have generally categorised the dose as either internal or external TL. The latter would be defined as the mechanical workload placed on an athlete, while the former would be defined as the physiological or psychological response to the imposed demands of training (Huxley *et al.*, 2014; Soligard *et al.*, 2016). Training and match loads are typically obtained utilising measures of external TL in isolation, or in combination with a measure of internal TL (Gabbett, 2004; Huxley *et al.*, 2014; Soligard *et al.*, 2016).

It is important to understand that identical external TL could elicit considerably different internal TL in two different athletes (White, 2017). The training stimulus (external load prescribed) may be appropriate for one athlete, but inappropriate for another (either too high or too low). Thus, the monitoring of TL should be done on an individual basis, utilising an individual's relative TL rather than generalised

absolute TL and focus should be on the metrics that will provide the best insight for an individual or a team (Gabbett, 2004; Soligard *et al.*, 2016; Bourdon *et al.*, 2017).

2.2 INTERNAL TRAINING LOAD MONITORING

The internal load is the individual physiological and/or psychological response to external loads which are cumulative with daily life stressors and other environmental and biological factors (Huxley *et al.*, 2014). It includes objective measures such as heart rate response, as well as subjective psychophysiological measurements such as ratings of perceived exertion (RPE).

2.2.1 Psychological measures for monitoring training load (subjective)

Due to differences in the psychological and physiological composition of individual athletes and their recovery potential, exercise capacity, non-training/life stressors, and stress tolerance, it is vital that athletes are evaluated individually (Bourdon *et al.*, 2017). The method(s) used need to account for the subtle individual differences and changes in athletes during training and the competition process (Bourdon *et al.*, 2017).

Meeusen *et al.* (2013) reported that psychological indicators are more sensitive and consistent than physiological indicators. In addition, psychological measures can be collected, applied and reported in a more time-efficient manner compared to physiological indicators such as blood markers, which can take days or weeks to assess (Bourdon *et al.*, 2017).

Common methods used within sessions to evaluate the psychological impact of training and match load include Borg's Rating of Perceived Exertion (RPE), and at a later stage the Session RPE (sRPE), Profile of Mood States (POMS), and the Recovery-Stress Questionnaire for Athletes (RESTQ-Sport) (Borg, 1970; Borg, 1973; Borg, 1982; McNair *et al.*, 1992; Kellman & Kallus, 2001). Borg's RPE was included into this section due to the measures psychophysiological nature, in which both psychological factors (e.g., anxiety, stress) and physiological variables (e.g., heart rate) affect the given RPE (Bourdon *et al.*, 2017).

2.2.1.1 Rating of perceived exertion (RPE)

Borg's RPE scale is commonly used in exercise testing, training, and rehabilitation to assess the level of perceived exertion of an individual and is popular in both individual and team sports (Borg, 1998). The RPE was envisioned to assess inter-individual differences in exercise intensity, with regards to certain psychophysical functions, with the assumption being that psychological strain increases linearly with exercise intensity and that perception follows the same linear pattern (Borg, 1970; Borg, 1973).

The original Borg RPE scale was scored on a scale from 6-20, with six and 20 representing the start and end points, respectively. Every uneven number on the scale was associated with a verbal anchor: e.g., number seven was 'extremely light' and number 19 was 'extremely hard' (Borg, 1970). Research found that the original RPE scale had strong correlations ($r = 0.80-0.90$) with heart rate (HR) and other physiological variables like blood lactate concentrations (Borg & Noble, 1974; Mihevic, 1981). Thus, the Borg RPE scale range from 6-20 could be used to estimate HR ranges from 60-200 beats/min (e.g., Borg RPE of 10 \times 10 = 100 beats/min). Despite this relationship, it was found that the 6-20 Borg RPE scale may be perceived as cumbersome, and that a simple category-ratio scale would be more beneficial (Borg, 1982). A category-ratio scale would make RPE easier to use for the lay population and would not be restrictive to those with a lack of mathematical and/or technical terminology, thus the 0-10 scale RPE (CR-10 scale) was established (Borg, 1982).

According to Foster *et al.* (2001) a simple method for quantifying internal TL in athletes is to have the athletes subjectively rate the intensity of an entire training session using a RPE according to the category-ratio scale (CR-10 scale). A CR-10 scale intensity value is then multiplied by the training duration (volume in minutes) to create a single measure of internal TL (sRPE) in arbitrary units (AU). For example, if a player completed a 100 minute training session at an intensity (RPE) of 5/10, his/her measure of internal TL would be calculated as follows (Foster *et al.*, 2001):

$$\text{Internal Training Load (AU)} = \text{Intensity (RPE)} \times \text{Volume (min)}$$

$$\text{Internal Training Load (AU)} = 5 \times 100$$

$$\text{Internal Training Load} = 500 \text{ AU}$$

This method compares favourably to other methods of quantifying internal TL in endurance (Foster *et al.*, 1995; Foster *et al.*, 2001; Oliveira Borges *et al.*, 2013), team sport (Impellizzeri *et al.*, 2004; Alexiou & Coutts, 2008) and resistance-trained athletes (Day *et al.*, 2004). In addition, Coutts *et al.* (2009), suggested that the sRPE method better reflected the internal TL placed on athletes compared to either heart rate (HR) or blood lactate measurements. However, for an instrument of TL to be truly useful in the monitoring process it needs to be both valid and reliable (Bourdon *et al.*, 2017).

The validity and reliability of sRPE in calculating internal load have been assessed in a variety of different sporting codes, both in individual sport as well as in team sport. Table 2.1 below summarises the findings of these independent studies.

Table 2.1 Summary of sRPE validity and reliability

Sport	Variable comparison	Valid & Reliable	Authors
Australian football	sRPE vs. HR	M - H	Scott <i>et al.</i> (2013)
Soccer	sRPE vs. HR	M - H	Impellizzeri <i>et al.</i> (2004)
Water Polo	sRPE vs. HR	M - H	Lupo (2014)
Taekwondo	sRPE vs. HR vs. [La]	M - H	Perandini (2012)

Abbreviations: M-medium, H-high. [La] = lactate concentration.

All of these studies found that sRPE is a valid indicator of global internal TL and that the CR-10 scale is a valid method of quantifying sRPE internal TL in team and individual sports (Impellizzeri *et al.*, 2004; Scott *et al.*, 2013; Perandini, 2012; Scott *et al.*, 2013; Lupo, 2014). Additionally, Lambert and Borresen (2006) indicated that although HR may be a more accurate method of calculating internal

TL, the subjective measure of sRPE remains useful for various types of exercise. Martin and Anderson (2000) also suggested that sRPE could be more sensitive to accumulated fatigue than HR.

Therefore, the revised literature indicates that the sRPE method as posited by Foster *et al.* (2001) for quantifying internal TL is a valid and reliable measure. The validity and reliability of the sRPE method are due to the psychophysiological nature of RPE in which both psychological factors (e.g., anxiety, stress) and physiological variables (e.g., heart rate) affect the given RPE and in turn provide an accurate global internal TL measure (sRPE).

2.2.1.2 Profile of mood states (POMS)

Psychological monitoring instruments are important to assess an individual's mood, the need for recovery, and a specific individual's current life circumstance (Kentta *et al.*, 2006). The advantage of psychometric instruments compared to common physiological monitoring (e.g., blood analysis, heart rate analytics) is that these instruments provide information quickly so that practitioners can make timely alterations to TL to address any issues highlighted by an athlete. The POMS is one such psychometric instrument that can be applied across sports and genders (McNair *et al.*, 1992).

The POMS provides a self-assessment for mood and stress and is frequently used to monitor the training stress imposed on an athlete (McNair *et al.*, 1992). The questionnaire itself is valid and reliable, with acceptable criterion validity having been reported (Terry *et al.*, 2003; Bourdon *et al.*, 2017). Training imposes stress on an athlete, which inevitably shifts their physical and psychological well-being along a continuum. This continuum progresses from acute fatigue and spans to overreaching and ultimately overtraining syndrome (Fry *et al.*, 1991; Coutts & Cormack, 2014). The POMS itself is a 65-item questionnaire in which responses are rated on a Likert scale of one (not at all) to four (extremely). The POMS subjectively provides a measure of total mood disturbances and six mood states (i.e., tension, depressed mood, anger, vigour, fatigue and confusion). Additionally, the test offers an easy assessment of the early indicators of overtraining in athletes and is sensitive to impaired well-being in response to

changes in acute and chronic TL (O'Connor *et al.*, 1989). However, the subjective POMS test does not provide information about the causes of overtraining (Kellman, 2010).

The revised literature highlighted the need for overloading in order to achieve maximal performance levels. The challenge is to provide these overload stimuli when required, and to limit the onset of staleness and excessive fatigue. Subsequent studies found that mood state disturbances increased in a dose-response manner as the training stimulus increased, and that these mood state disturbances fell back to baseline with a reduction in TL (Morgan *et al.*, 1987). These findings were supported by later studies which found that the monitoring of mood states with the POMS allowed for the identification of impaired athlete well-being. The impaired athlete well-being was as a result of increases in TL, and conversely improved athlete well-being was due to reductions in TL (Martin *et al.*, 2000; Coutts *et al.*, 2007). This highlights the importance of the POMS for on-going TL monitoring protocols, because it provides practitioners with a 'snapshot' of an athlete's well-being as a result of the stress imposed by the acute load of training. However, the POMS also offers a 'snapshot' into an athlete's progression towards overtraining syndrome, as a response to the fatiguing nature of high chronic TL without adequate periods of rest and recovery.

The ability of a subjective test like the POMS to reflect both acute increases and decreases in athlete well-being, combined with its sensitivity to changes in well-being in response to chronic TL, make it a potentially valuable TL monitoring tool to prevent injury and thus improve performance.

2.2.1.3 Recovery-Stress Questionnaire for Athletes (RESTQ)

The Recovery-Stress Questionnaire for Athletes (RESTQ) was developed by Kellman *et al.* (2001) in order to assess an athlete's perception of the balance between stress (induced by training and competition) and recovery phase. The design of the RESTQ is based on the stress and injury model, which assumes that a culmination of stress factors in different areas of life results in a maladaptive psychophysical state if there is no sufficient possibility of recovery between the imposed demands of training and competition (Saw *et al.*, 2015).

The RESTQ consists of general and sport specific stress and recovery scales. There are seven general stress scales (general stress, emotional stress, social stress, conflicts/pressure, fatigue, lack of energy, physical complaints) five general recovery scales (success, social recovery, physical recovery, general well-being, sleep quality), three sport-specific stress scales - (disturbed breaks, emotional exhaustion, injury) and four sport-specific recovery scales - (being in shape, personal accomplishment, self-efficacy, self-regulation) (Kellman & Kallus, 2001; Saw *et al.*, 2015). Items on the RESTQ for athletes are rated on a Likert-type scale ranging from zero (never) to six (always). The rating scale is based on how often a specific event mentioned in the item occurred in the last three days/nights. The scales were assessed for both internal consistency and test-retest reliability and were shown to have good internal consistency ($r = 0.67-0.89$) and high test-retest reliability ($r > 0.79$) (Saw *et al.*, 2015).

This method of quantifying internal TL in order to assess the relationship between stress and injury imposed by training and match loads has been investigated in a wide variety of sports. Studies found that changes in training volume were reflected by significant changes in RESTQ-Sport scales. Specifically, in rowing, it was found that increases in training volume were reflected in elevated stress and reduced recovery scores measured by the RESTQ-Sport. Kellmann and Gunther (2000) and Kellmann and Kallus (2001) reported significant increases in stress and decreases in recovery when TL increased, and vice versa.

2.2.2 Physiological measures for monitoring training load (objective)

In order to directly quantify TL it is useful to utilise objective physiological measures. These forms of load monitoring take out the athlete's perception of the prescribed TL, and quantify it utilising physiological measures, which correspond to how an athlete's physiological systems react to a specific stimulus. Common measurements used to evaluate the physiological impact of training and match load include HR methods, biomechanical measures and neuromuscular measures of fatigue.

2.2.2.1 Heart rate (HR) based methods

Monitoring HR is one of the most common objective methods for quantifying internal load in athletes (Halson, 2014). The use of HR monitoring during exercise is based on the linear relationship between HR and the rate of oxygen consumption during steady-state exercise (Hopkins, 1991). Methods utilising HR have been developed to allow practitioners to accurately quantify TL in individuals. These methods potentially provide a clear indication of how an athlete has physiologically responded to a prescribed external load stimulus. However, HR based monitoring methods present limitations that should be considered before using HR to quantify internal TL.

The limitations of HR include:

- The potential variability and lack of reliability of different HR monitoring systems (e.g., Polar vs. First Beat) (Foster *et al.*, 2001)
- The lack of athlete acquiescence or buy in (athletes refusing or forgetting to wear HR monitors which may result in lost data) (Foster *et al.*, 2001)
- The technical failure of the HR monitoring equipment (e.g., uncharged batteries, broken receivers etc.) (Foster *et al.*, 2001)
- The cost for large squads of athletes (Halson, 2014)
- Potentially inaccurate evaluation of very high-intensity exercise such as weight training, high-intensity interval training (due to delayed HR response), and plyometric training (Foster *et al.*, 2001)
- And the day-to-day variation of an individual's HR as a result of training status (Halson, 2014), environmental conditions, diurnal changes, hydration status, altitude, medication and, diet (Robinson *et al.*, 1991; Achten *et al.*, 2003).

All of these factors need to be carefully considered and accounted for in order to improve the validity and reliability of HR based monitoring methods. The various methods will be discussed in further detail in the paragraphs below.

i. Training Impulse (TRIMP)

TRIMP integrates training intensity and duration into a single quantified unit of training, deemed the dose (Banister *et al.*, 1975). TRIMP allows practitioners to

quantify a TL utilising an athlete's HR response to an imposed demand. This objective quantification of TL allows for more appropriate TL prescription and progression, resulting in optimized performance and reduced injury incidence (Gabbett, 2016a).

There are three main methods of calculating TRIMP, namely, Banister's TRIMP (Banister *et al.*, 1975), Edwards' TRIMP (Edwards, 1993) and Lucia's TRIMP (Lucia *et al.*, 2003). Banisters TRIMP takes into consideration the intensity of exercise as calculated by HR and the duration of exercise. The calculation derived by Banister can be seen below (Banister *et al.*, 1975):

$$\text{Banister's TRIMP} = \text{duration (min.)} \times \left(\frac{HR_{ex} - HR_{rest}}{HR_{max} - HR_{rest}} \right) \times 0.64e^{1.92x}$$

Where HR_{ex} = average HR during exercise.

HR_{rest} = HR at rest.

HR_{max} = predetermined maximal HR.

$e = 2.712$.

$$x = \left(\frac{HR_{ex} - HR_{rest}}{HR_{max} - HR_{rest}} \right)$$

Edwards' TRIMP differs from Banisters in that the calculation has a zone based method for calculating TL. The time spent in five pre-defined arbitrary zones is multiplied by arbitrary coefficients to quantify internal TL. The calculation of Edwards TRIMP can be seen below (Castagna *et al.*, 2011):

Edwards' TRIMP = (duration in zone 1) × (1+duration in zone 2) × (2 + duration in zone 3) × (3 + duration in zone 4) × (4 + duration in zone 5) × 5

Where Zone 1 = 50% to 60% HR_{max}

Zone 2 = 60% to 70% HR_{max}

Zone 3 = 70% to 80% HR_{max}

Zone 4 = 80% to 90% HR_{max}

Zone 5 = 90% to 100% HR_{max}

Lucia's TRIMP is different to Banister's and Edwards' TRIMP in that the measure of TL is based on individually determined lactate threshold's and the onset of blood lactate accumulation (OBLA). This method uses the duration spent in each of the three HR zones (zone 1: below the ventilatory threshold (VT), zone 2: between the VT and the respiratory compensation point, and zone 3: above the respiratory compensation point), multiplied by a coefficient (k). The value of (k) is relative to each zone, thus, zone 1: k = 1, zone 2: k = 2 and for zone 3: k = 3. The Lucia's TRIMP formula is as follows:

$$\text{Lucia's TRIMP} = (\text{duration in zone 1} \times 1) + (\text{duration in zone 2} \times 2) + (\text{duration in zone 3} \times 3)$$

Various studies have utilised TRIMP to quantify the internal training and match loads of athletes. Initially, the research conducted was primarily focused on endurance athletes with prolonged training schedules. These athletes need to optimise performance for relatively short competition period (relatively short when compared to a soccer season of 47 weeks) from a single-day event (e.g., athletics meet) to an event lasting a few weeks (e.g., cycling tour). However, TRIMP has also been utilised to quantify the internal load of team sport athletes (Impellizzeri *et al.*, 2004; Scott *et al.*, 2012; Rodríguez-Marroyo & Antonan, 2015). This research has identified a number of limitations in using TRIMP, specifically in soccer.

Firstly, with regards to Banister's TRIMP, the use of average HR may not reflect fluctuations in HR that occur during intermittent sports, like soccer. According to Stolen *et al.* (2005), the average exercise intensity in soccer matches is approximately at the anaerobic threshold of 85% of HR_{max}. Additionally, it has been reported that HR can reach intensities close to HR_{max} (Ascensao *et al.*, 2008). Secondly, Banisters method makes use of generic equations for men and woman. This implies that the gender is the only factor which individualises

athletes, and therefore does not necessarily take into consideration the individual differences that may affect TL.

Edward's TRIMP has similar limitations, where Banister utilises average HRs and generic gender differences, Edwards' TRIMP makes use of unvalidated arbitrary HR zones which don't necessarily correspond to any physiological measures (Herrera-Valenzuela & Valdés-Badilla, 2016). Similar issues are presented by Lucia's TRIMP, as the weighting of the three zones remain relatively arbitrary. Furthermore, this weighting implies that adaptations to training would be the same, regardless of the zone in which an athlete trains. This implication is in direct opposition with revised literature, which showed how a 5% difference in training intensity (95% $\dot{V}O_{2max}$ vs. 100% $\dot{V}O_{2max}$) produced different training adaptations (Denadai *et al.*, 2006). Therefore, Lucia's TRIMP may be a sub-optimal method to monitor internal TL in intermittent team sport athletes.

Numerous studies in team sport have attempted to validate different TRIMP measures against the sRPE method of quantifying internal TL. The findings of these studies suggest that the sRPE method may be considered a better indicator of global internal TL compared to TRIMP measures (Rodríguez-Marroyo & Antonan, 2015). This is due to certain circumstances such as the cognitive demands, motivational status and the intermittent nature of soccer, and the inability of HR measures to account for these factors (Impellizzeri *et al.*, 2004). Thus, when the limitations are taken into account, TRIMP seems to be unable to accurately and reliably assess exercise intensity and internal TL in intermittent team sports. This, coupled with the financial cost and considerable expertise required to utilise TRIMP, means it may not be the most effective method of quantifying internal TL, specifically for soccer players.

ii. Heart rate variability (HRV)

Heart rate variability (HRV) is the time difference between successive heartbeats (HB). This period is also known as the R-R interval or the inter-beat interval and is graphically depicted below in Figure 2.1. HRV was initially studied by health science researchers, who found correlations with mortality and severe arrhythmic complications during the post-infarction period (Wolf *et al.*, 1978). Subsequently,

HRV has been associated with athletic performance and recovery (Pinna *et al.*, 2007).

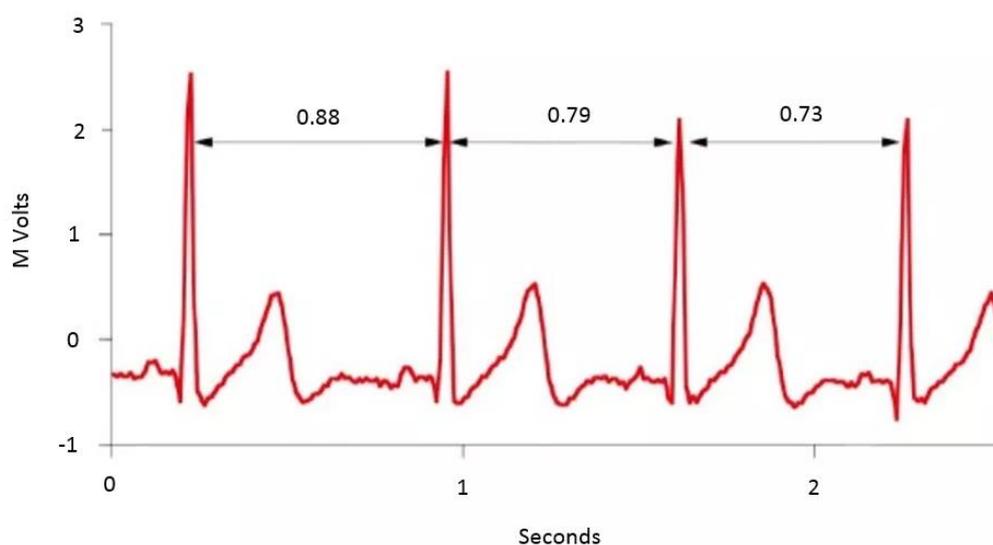


Figure 2.1 Example of the variation observed between HB

The HRV measures provide important information pertaining to the function of the autonomic nervous system (ANS), (i.e., the balance between the sympathetic nervous system (SNS) and para-sympathetic nervous system (PNS)), in a non-invasive manner (Risk *et al.*, 2001). HRV is the most reliable measurement of ANS function (Risk *et al.*, 2001) and an increase in HRV represents a positive adaptation or improved recovery status, while a reduction in HRV reflects stress and a reduced recovery status. This allows practitioners to monitor systemic fatigue and recovery as a result of training and match load demands imposed on an athlete (Aubert *et al.*, 2003).

Initially, HRV was measured utilising electrocardiogram (ECG). However, due to the subsequent development of telemetric technology, practitioners can now make use of smartphone applications to reliably measure HRV (Flatt & Esco, 2013; Heathers, 2013). There are a variety of methods used to calculate HRV, commonly utilised methods include: the root-mean square difference of successive normal R-R intervals (RMSSD) (Camm *et al.*, 1996; Aubert *et al.*, 2003), the high-frequency power (HFP) and the standard deviation of instantaneous beat-to-beat R-R interval variability (SD1) (Camm *et al.*, 1996;

Bellenger *et al.*, 2016). However, research has indicated that the most common and reliable method is the RMSSD (Aubert *et al.*, 2003). In terms of validity and reliability, HRV is a valid and reliable measure of ANS function and studies have shown that HRV is a reliable measure of ANS function for sedentary adult and elite athlete populations (Cottin *et al.*, 1999; Risk *et al.*, 2001; Nakamura *et al.*, 2017).

Due to the usefulness of HRV to practitioners (because it reflects ANS function and stress), the reviewed literature suggested that monitoring of HRV can assist in gauging an athlete's recovery status (Chen *et al.*, 2011), help determine if an athlete is overtraining (Bellenger *et al.*, 2016), identify athletes that aren't responding to training, predict an athlete's performance for a particular exercise bout, and predict when an athlete is at a higher risk of injury and illness (Ross, 2008; Flatt, 2012; Gisselman *et al.*, 2016).

In summary, HRV reflects the variation in time between an individual's HB, and the HRV score (low or high) can be used to assess an athlete's recovery status. Additionally, HRV can be utilised to quantify the internal physiological response an athlete has to a said external TL - i.e., increases in external TL (e.g., intensity of training or longer duration) directly affects the ANS and the associated HR-related measures (Cornforth *et al.*, 2015; Bisschoff *et al.*, 2016). Therefore, the revised literature indicates that HRV is a useful tool to monitor recovery in order to prevent injury and enhance performance, while quantifying an internal physiological response to a said external TL.

2.2.2.2 Biochemical measures of training load

Research has indicated that various biochemical, hormonal, and immunological markers obtained from blood and/or saliva might assist practitioners in assessing TL. Specifically, these markers are implicated in quantifying the acute responses to load (Twist & Highton, 2013). This ability to assess an athlete's acute response to an imposed TL, may assist practitioners in monitoring fatigue and minimising fatigue and illness (Halsen, 2014).

Common measures collected and analysed include creatine kinase (CK), salivary testosterone and cortisol, and blood lactate concentrations ([La]) (Twist & Highton, 2013; Halson, 2014). Serum CK concentration has previously been measured due to the simplicity of collection and analysis. This measure is indicative of tissue damage and researchers have recommended it as a useful measure in order to monitor acute recovery from rugby match play (McLellan *et al.*, 2011a). However, the variability of CK concentrations in response to training is very high between athletes and measurements, and there is a poor temporal relationship between muscle recovery and CK concentrations (Twist & Highton, 2013). CK has additionally been correlated with the number of contact moments in rugby (e.g., tackles). As a result, CK concentrations are unable to distinguish between muscle damage as a result of sport-specific activity and damage caused by the trauma of a contact (McLellan *et al.*, 2011b; Twist *et al.*, 2012). The high degree of variability, poor specificity and poor temporal correlation with TL limits the practical usefulness of CK measurements.

Salivary cortisol and testosterone measurements have been shown to have a relationship with performance, specifically in the case of overreached athletes (Twist & Highton, 2013). Additionally, the literature further indicated that the ratio between cortisol and testosterone may be more useful, as it provides a better understanding of the balance between anabolic and catabolic states post-competition, which may assist practitioners in optimising recovery strategies (McLellan *et al.*, 2011a; 2011b). Regular saliva monitoring may therefore provide useful information about the health and wellbeing of rugby players. In addition, this practice may be useful in a research setting as it provides insights into fatigue which may improve performance (if fatigue is limited) and limit the risk of injury (Twist & Highton, 2013). However, these measures have numerous limitations in that they are expensive, time-consuming, and practically challenging in an applied sports performance environment (Twist & Highton, 2013).

In order to assist practitioners in quantifying the intensity of a training bout, blood [La] has been shown to be sensitive to changes in exercise intensity and duration (Beneke *et al.*, 2011). However, there are numerous limitations in the use of lactate concentrations, including the unreliability of portable lactate analysers,

and numerous factors which may influence the lactate concentration such as ambient temperature, hydration status, diet, muscle glycogen concentrations, mode of exercise, fatigue, prior exercise bouts and the amount of muscle mass recruited to name a few (Swart & Jennings, 2004; Borresen & Lambert, 2008).

In summary, the use of blood and salivary measurements as indicators of internal TL, while theoretically useful, present numerous challenges and limitations. In addition, these measures can be costly, time-consuming and impractical in an applied sports medicine environment (Twist & Highton, 2013).

2.2.2.3 Neuromuscular measures of training load

Measures of neuromuscular function (NF) are often utilised in the team sport environment to assess the impact of training and match loads (Twist & Highton, 2013). Research indicated that the jump test (countermovement (CMJ) / squat jump), sprint performance, and isokinetic and isoinertial dynamometry are often utilised in the team sport environment to assess NF (Twist & Highton, 2013). These neuromuscular variables, with special reference to CMJ measures have previously been described and have been shown to be reliable and useful in detecting fatigue in team sport athletes (Cormack *et al.*, 2008a; 2008b; 2008c).

Tests such as the CMJ have become popular due to their efficiency (in terms of duration of the test and ease of application) and not being aversive for athletes in terms of test performance requirements (Twist & Highton, 2013). Practitioners commonly utilise variables such as mean power, peak velocity, peak force, jump height, flight time, contact time, and rate of force development from jump tests such as the CMJ (Taylor, 2012). Neuromuscular assessments are useful because they reflect the stretch-shortening capability of the lower-limb muscles, which allows practitioners to evaluate muscle fatigue and impaired muscle function (McLellan *et al.*, 2011b; Twist *et al.*, 2012).

A review of the literature demonstrated that neuromuscular measures of TL may be useful, and indicated that sports medicine practitioners often utilise these measures (Twist & Highton, 2013). However, the cost, portability and lack of sport-specific movement while conducting neuromuscular testing like CMJ using

a force platform were indicated as limitations (Halson, 2014). These limitations need to be weighed up and assessed according to the demands/requirements of the sport team, club or organisation (Halson, 2014).

2.3 EXTERNAL TRAINING LOAD MONITORING

The external load objectively quantifies an external stimulus applied to an athlete (i.e., the measurable physical work performed during an exercise bout) (Gabbett, 2004). Sports scientists and sports medicine practitioners typically measure external load in order to quantify training or competition load. This may assist with improvements in periodisation and planning and thus, contribute to performance enhancement and injury reduction in sportsmen/women (Soligard *et al.*, 2016).

The measurement of external load typically involves quantifying training and match loads as an absolute value by, only considering the mechanical work an athlete has performed in a specific time (training session and/or competition) (Soligard *et al.*, 2016). Practitioners tend to measure external TL utilising volume metrics such as the hours of training, distance run, high speed running distance, repetitions performed or number of sprints, etc. (Soligard *et al.*, 2016). This is in comparison to internal measures of TL, which generally assess the internal physiological and psychological response to the external TL stimulus i.e., mechanical work (Borresen & Lambert, 2008).

The internal TL allows practitioners to assess an athlete's physiological response relative to the external TL imposed, while the measurement of external TL is vital in order to understand the work completed and capabilities and/or capacity of an athlete. Due, to the advancement of technology, a game-changer in monitoring the external load is the use of the global positioning systems (GPS) (Cummins *et al.*, 2013).

2.3.1 Global positioning systems (GPS)

GPS is a satellite-based navigational technology which, like many other technologies, was originally developed and utilised for military purposes (Scott *et al.*, 2016). The development and refinement of portable GPS units has allowed for a wider application of this technology in a variety of settings, including elite

sport. GPS allows for three-dimensional movement of an individual athlete or team to be tracked over time in air-, water-, or land-based environments (Schutz & Herre, 2000; Larsson, 2003; Gray *et al.*, 2010). The refinement of these GPS systems has provided additional means for sports medicine practitioners to describe and understand the spatial context of physical activity (Cummins *et al.*, 2013).

GPS was first utilised in sport to track athlete movements in 1997 (Schutz & Chambaz, 1997), and has since become a must-have technology in elite team sport environments. The demand for this technology is due to the fact that it provides comprehensive and real-time data of on-field player performance during an exercise bout (Cummins *et al.*, 2013).

GPS has been utilised extensively in a variety of team sports, such as rugby league, rugby union, dance, Gaelic football, AF, cricket, hockey, American football and soccer. This technology allows for practitioners embedded within these sports, to objectively quantify external TL, which may assist in assessing the level of fatigue and physical stress on individual athletes, and to study match performances. Additionally, it enables the evaluation of different positional demands, the quantification of training intensities, and the monitoring of changes in player physiological and/or biomechanical demands (McLellan *et al.*, 2011c). Athlete external loads, as derived via GPS can be used in addition to tactical information (from coaching staff) and internal load (physiological and psychological impact/response), to characterise competitive match play (McLellan *et al.*, 2011c).

In order to enhance the usefulness of GPS technology to quantify and define elite athlete's external TL demands, the technology was integrated with triaxial accelerometers (Scott *et al.*, 2016). This integration of accelerometers enabled these devices to capture information on work rate patterns, more accurate acceleration and deceleration information, and integrated mechanical loads (Cummins *et al.*, 2013). The triaxial accelerometer measures a composite vector magnitude, expressed as a G-force, by recording the sum of accelerations measured in three axes (X, Y and Z planes) (Waldron *et al.*, 2011). This

development allowed practitioners a more comprehensive view into the demands of elite sport and opened new avenues for athlete monitoring. However, despite GPS's apparent usefulness, questions were raised with respect to the technology's reliability and validity.

2.3.1.1 The validity of Global Positioning Systems (GPS)

The validity of an instrument reflects the ability of said instrument to accurately measure what it intends to measure (Johnstone *et al.*, 2014; Scott *et al.*, 2016). Validity measurements are presented as the standard estimate of error (SEE), standard error of measurement (SEM), coefficient of variation (CV), or the percentage of difference of the mean from criterion measures (Scott *et al.*, 2016). There are two main components of GPS validity investigations, namely - distance validity (the GPS system's ability to accurately measure distance) and speed/velocity validity (the GPS system's ability to accurately measure the velocity at which athletes cover a distance) (Scott *et al.*, 2016). The following sections will focus on the above stated investigation components and only reference studies that test validity in a team sport simulated context, as the author believes this most appropriate for the current study.

i. Distance validity

GPS systems have been shown to accurately report total distances during team sport activities (e.g., training and matches) (Scott *et al.*, 2016). Jennings *et al.* (2010a) found that when following a circuit designed to create general movement patterns and intensities commonly observed in team sport, 1Hz GPS devices accurately reported total distance measures (SEE = 3.6%). Further research in soccer, found that 1Hz GPS devices accurately reported total distances in courses specifically designed to mimic the actions of soccer defenders, midfielders, and forwards (1.3-3.0% SEE) (Portas *et al.*, 2010). Portas *et al.* (2010) also showed that 5Hz GPS devices produced valid measurement of position-specific distances of soccer defenders (SEE = 2.2%), midfielders (SEE = 1.5%), and forwards (SEE = 1.5%). Interestingly, the reviewed literature indicated that distance validity was reduced when attempting to measure short distances or distance covered at high velocities, however, the reduced validity

observed in 1Hz GPS units were improved upon when compared to the increased sampling rates of 5Hz devices (Portas *et al.*, 2010; Scott *et al.*, 2016).

The increased validity observed with higher sampling rates was further improved upon with the use of 10Hz GPS devices, and evidence suggests that 10Hz devices were able to better quantify short to moderate distances at higher velocities with higher accuracy compared to 1Hz and 5Hz devices (Vickery *et al.*, 2014; Scott *et al.*, 2016). The higher sampling rate provided superior validity for measuring distance and can be seen as preferable in team sport environments (Scott *et al.*, 2016).

ii. Speed/velocity validity

GPS devices can accurately measure velocities during sprints which occurred after moderate velocity motion and those that involved accelerations (CV < 10%) (Waldron *et al.*, 2011; Scott *et al.*, 2016). However, the accuracy of reported velocity measurement was reduced for running that involved the slowing of motion (deceleration) or running from a standing or slow moving start when athletes were equipped with 5Hz GPS devices (Varley *et al.*, 2012). Furthermore, Vickery *et al.* (2011) identified that 5Hz devices possessed poor validity for measurements of speed, in which the devices underestimated mean speeds during field-based team sport movements. However, despite reduced validity with regards to mean speed measurements, Vickery *et al.* (2011) found that peak speed measurements did not differ from the criterion measures. Therefore, in summary 5Hz GPS devices provide valid measurements only under specific conditions (e.g., instantaneous velocity as a result of an acceleration after moderate velocity motion) however, literature suggested that 10Hz GPS devices may have overcome some of the problems observed with 5Hz GPS devices.

Ten Hertz GPS devices have been shown to possess good to moderate validity for measures of instantaneous velocity during constant velocity running and running which involved accelerations between 0-4 m.sec⁻² (Varley *et al.*, 2012; Akenhead *et al.*, 2014). However, as with 5Hz GPS devices, 10Hz GPS devices have been shown to possess poor validity when measuring:

- Peak speed and mean speed during team sport running and running which involved change of direction (Johnston *et al.*, 2014; Vickery *et al.*, 2014)
- Instantaneous velocities when deceleration was occurring (Varley *et al.*, 2012)
- And interestingly, reduced validity for accelerations greater than 4 m.sec⁻² (Akenhead *et al.*, 2014).

However, it is important to note that despite the degree of error reported when measuring instantaneous velocity, 10Hz GPS devices can at least accurately determine that an acceleration or deceleration occurred (Akenhead *et al.*, 2014). Therefore, researchers can determine the number of acceleration and deceleration exposures undertaken by an athlete during a match, and report it thusly, as opposed to quantifying the magnitude in terms of distance and duration (Akenhead *et al.*, 2014).

2.3.1.2 The reliability of Global Positioning Systems (GPS)

Reliability refers to the reproducibility of values of a test on repeat occasions (Hopkins, 2000). It is important that GPS devices are reliable in real-life settings so that measurements are consistent, which allows for comparison between players (inter-unit) and between sessions (intra-unit) (Scott *et al.*, 2016).

The literature indicated that 10Hz GPS devices were able to repeatedly report accurate and reliable distances covered at high velocities while displaying good to moderate intra-unit reliability, overcoming the limitations of 1Hz and 5Hz GPS systems. Additionally, Varley *et al.* (2012) found that when using 10Hz GPS devices to measure instantaneous velocities during running, all noise values (CV) were much smaller than the signal values (SWC), which indicated that that 10Hz GPS devices were sensitive enough to detect all physiologically significant changes in velocities. Johnstone *et al.* (2014) found that the inter-unit reliability of 10Hz GPS devices was good when measuring peak speed during team sport simulated circuits (TEM = 1.6%, ICC = 0.97). The reviewed literature further highlighted that during team sport simulations the inter-unit reliability of all devices improved, which indicated that data from separate devices may be compared with confidence during team sport training session and matches (Scott *et al.*, 2016).

Considering the above reliability findings, it is recommended that the same unit be used to monitor an individual athlete over the desired timeframe in order to address any within-unit reliability issues (Jennings *et al.*, 2010b). Despite the limitations of GPS technology highlighted above, researchers have still indicated that GPS data is accurate and suitable for use in the measurement of intermittent physical activity during intermittent field sports, such as soccer and Gaelic football (Malone *et al.*, 2014).

2.3.1.3 Global Positioning Systems (GPS) metrics and training load monitoring

i. Total distance (TD)

The TD in meters (m) travelled by an athlete in training and match play was historically one of the first GPS variables measured and as such, is the most commonly reported variable (Cummins *et al.*, 2013). The literature identified between-sport differences in TD covered during competition. Cricket players in one day international cricket covered the greatest distance with 15 903 m (Petersen *et al.*, 2011), followed by Australian football (AF) with 12 939 m (Coutts *et al.*, 2010). Soccer demonstrated a higher TD during matches than rugby union (Cummins *et al.*, 2013). The TD differences between players from various competitive levels (i.e., elite, semi-professional, and junior) was also significant. Elite players were found to cover more TD compared to junior and semi-professional athletes, for both rugby union and soccer (Buchheit *et al.*, 2010; Hartwig *et al.*, 2011; Sua´rez-Arrones *et al.*, 2012). In addition to the differences between athletic skill levels, researchers found positional differences (e.g., backs vs. forwards) in TD in team sports. McLellan *et al.* (2011c) identified that professional rugby league backs covered on average 5 747 m, which is 16.9% more TD than forwards (4 774 m), these findings were similarly observed in rugby union, in which backs covered 7.6% more TD than forwards (6 471 m and 5 853 m, respectively) (Austin & Kelly, 2013).

The distinction between sports, athletic ability and positional differences has led to research focusing on TD as a measure of external TL, and the relationship it has with injury incidence. The literature demonstrated that TD is a good measure of external TL, and has identified a relationship between TD and injury risk (Colby *et al.*, 2014; Bowen *et al.*, 2016; Gabbett, 2016a; Jaspers *et al.*, 2017). TD was

recorded for individual athletes and modelled as two, three and four-week cumulative load, as well as utilising the acute chronic workload ratio (ACWR); this method will be discussed in greater detail in the following section. These values were then analysed to identify and assess the relationship between TD and injury occurrence. This revealed that higher three-weekly cumulated loads were best correlated with an increased injury risk in AF (Colby *et al.*, 2014) and rugby union (Gabbett, 2016a). In soccer high one-, two- and three-weekly cumulated loads were identified as risk factors for injury (Bowen *et al.*, 2016; Jaspers *et al.*, 2017).

In summary, TD can identify differences between sports, the calibre of an athlete, positional differences, and has a strong correlation with injury incidence, therefore practitioners can utilise TD as an effective external TL monitoring variable.

ii. High speed running (HSR)

Due to workload characteristics and the demands of different team sports (e.g., soccer vs. rugby vs. AF, etc.), the HSR metric, is variably quantified and defined. According to Cummins *et al.* (2013) there are six categorised speed zones, ranging from zero to 36 km/h. Each of these speed zones are consecutive in nature and describes a movement activity (e.g., walking through to sprinting). Existing research demonstrates large variations between different sports, for example, speed zone four was reported for field hockey (Gabbett, 2010) and soccer (Buchheit *et al.*, 2010) at 7-18 km/h, while rugby union (Hartwig *et al.*, 2008) and AF (Aughey, 2011) reported higher velocities of 12-21 km/h and 14-20 km/h, respectively. Interestingly, according to Cummins *et al.* (2013) the majority of studies (n = 30 [85.6%]) concentrated on HSR in zone four and above.

Researchers have proposed HSR as an important variable to consider when quantifying an athlete's external TL and assessing any injury risk (Duhig *et al.*, 2016). Research to date has focused on utilising HSR as an external load variable and in predicting injury risk. Duhig *et al.* (2016), postulated that an athlete who performed greater HSR than that which they were accustomed to, based on the prior four-week period, demonstrated an increased likelihood of injury. Other

studies have since identified similar relationships between HSR and injury risk (Murray *et al.*, 2016).

In summary, HSR can be an important variable to monitor TL and evidence suggests that the variable has a relationship with injury risk. However, practitioners need to identify appropriate speed zones for the desired sport, and be aware that the ability of GPS to accurately measure velocity is diminished when there is a high rate of change in velocity (Varley *et al.*, 2012; Akenhead *et al.*, 2013). Thus, HSR variables should be utilised with caution.

iii. Acceleration and deceleration

These variables are measures of high-intensity stochastic exertions in sport (Cummins *et al.*, 2013). There is limited research relating to acceleration and deceleration monitoring in team sports, which can mostly be attributed to the inability of GPS to accurately measure these variables until the introduction of the 10 Hz accelerometer-integrated GPS units (Johnston *et al.*, 2014). A small number of studies have utilised these variables to analyse injury risk specific to soccer. It was reported that higher cumulative two-, three- and four-weekly loads for decelerations were associated with increased injury risk in the subsequent week (Jaspers *et al.*, 2017). It was also reported that when specific loading conditions concerning acceleration and decelerations were met, a protective effect was found for athletes (Jaspers *et al.*, 2017). Conversely, when these were exceeded the risk of non-contact injuries significantly increased (Bowen *et al.*, 2016). These external load variables therefore show some merit for athlete load monitoring, however, further research is required.

In conclusion, the utilisation of GPS by sports medicine practitioners has facilitated the collection of metrics that describe the physical demand and impacts the sport has on an athlete, both in training and in (Cummins *et al.*, 2013). This facilitation has allowed researchers to better understand the external loads athletes are under and identify higher injury risk periods. However, for GPS to be a useful and beneficial monitoring tool, practitioners need to understand the limitations of GPS (high-speed running involving rapid directional changes and

increasing velocity) and how to ameliorate these potential limitations (e.g., 5 Hz vs. 10 Hz units and within-unit reliability).

2.4 SUMMARY: TRAINING LOAD MONITORING

The review of TL monitoring literature has identified a variety of methods and measures that practitioners can utilise to monitor athlete load. No single marker of an athlete's response to load predicts maladaptation or injury consistently (Soligard *et al.*, 2016). As such, practitioners should measure both the internal and external load of their athletes (Saw *et al.*, 2015). The relationship between the internal load and the external load of an athlete may aid in revealing fatigue and limit injury risk, thereby enhancing performance (Bowen *et al.*, 2016).

The literature indicated a variety of measures for internal and external load, as well as highlighting any limitations or shortfalls. With regard to measuring an athlete's internal load, the CR-10 scale RPE coupled with Foster's method (sRPE) for calculating internal TL (Foster *et al.*, 2001), was shown to be valid and reliable. Additionally, the literature indicated that the measures take into account both the physiological and psychological state of an athlete. This has led to the sRPE method being deemed a valid indicator of global internal TL (Scott *et al.*, 2013). In order to compliment the global indicator of internal load, an equally robust external load method has been identified - GPS.

GPS measures allow for the mechanical load of an athlete to be quantified. The literature indicates that this method is valid and reliable, assuming practitioners consider the limitations. The current review highlighted the most common metrics (i.e., TD, HSR, accelerations and decelerations). In addition, evidence was provided to suggest that these metrics may aptly describe an athlete's external load and may also, when used for monitoring purposes, identify useful relationships. It has been proposed that while there is a relationship between high TL (both internal and external) and injury, the problem may not lie specifically with training, but potentially due to inappropriate TL being prescribed (Gabbett, 2016a). Therefore, an effective monitoring protocol should measure internal and external load, account for the demands placed upon an athlete, and indicate what

an athlete has done before. One such method may be the (ACWR) as proposed by Gabbett (2016a).

2.5 THE ACUTE CHRONIC WORKLOAD RATIO (ACWR)

After reviewing the relevant literature, it may be concluded that monitoring TL is vital in order to enhance performance and prevent injury (Gabbett, 2016a). An effective TL monitoring protocol should highlight the demands placed on an athlete at present, as well as consider the previous workloads that the athlete has been exposed to (Bowen *et al.*, 2014; Gabbett, 2016a; Soligard *et al.*, 2016). This snapshot of an athlete's TL may provide practitioners with important feedback to assist in the planning and periodisation of training in order to optimise physical conditioning and minimise injury risk.

One such method which could provide this important snapshot is the ACWR. The ACWR is a ratio which expresses the acute TL in comparison to the chronic TL and is comprised of an athlete's fitness (chronic TL) and fatigue (acute TL). The model itself was first proposed by Banister *et al.* (1975), and was previously known as the fitness-fatigue model, before being popularised by Gabbett (2010). The actual value presented by the ACWR has different implications, and can assist practitioners in understanding the preparedness of an athlete, and the relative injury risk of an athlete from week-to-week (White, 2017). Therefore, with a carefully planned intervention, practitioners may assist in the prevention of injury and enhance performance (White, 2017).

2.5.1 What is the acute chronic workload ration (ACWR)?

Banister *et al.* (1975) proposed a statistical model to explain an athlete's response to a given TL. This model proposed that performance of an athlete in response to training can be estimated by the difference between a negative function (fatigue) and a positive function (fitness). This fitness-fatigue relationship operates as follows (see Figure 2.2 below).

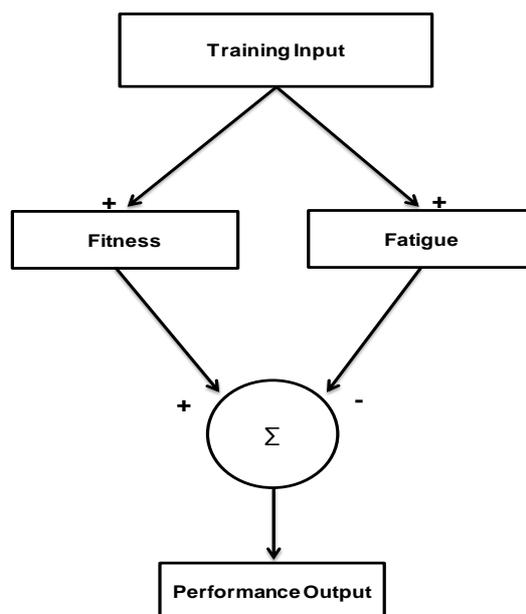


Figure 2.2 The dose-response systems model (fitness-fatigue) as proposed by Banister *et al.* (1975)

A quantitative unit of measurement (e.g., total distance (TD), expressed in m) is chosen to assess the amount or volume of training undertaken in a training session, which results in two physiological responses; a future increase in fitness, and an immediate increase in fatigue. The fatigue response is immediately evident on completion of a training bout in terms of the tiredness experienced (Morton, 1997). The fitness response, although concomitantly acquired, is not immediately experienced by the athlete. If the athlete ceases training, both the fatigue and fitness responses will decay. However, the rate of decay will differ according to the individual athlete's attributes. The fitness response may be enhanced and its decay prevented by successive bouts of training (Morton, 1997). Additionally, successive increments in fitness for the same training impulse becomes progressively smaller and fitness attains a plateau, unless the frequency and/or type of training is regularly increased. Inversely, successive bouts of training will maintain and increase the fatigue level towards a plateau, particularly if the bouts are severe or insufficiently spaced apart.

Building on this dose-response relationship and Banister's model, it was later suggested that the ideal training stimulus is one that maximises performance by

utilising an appropriate TL, whilst simultaneously limiting the negative consequences of training (i.e., injury and fatigue) (Morton, 1997). Therefore, it is important for practitioners to understand and monitor TL so that they can gauge their athletes past and present fitness levels. In other words, to express what they have previously done and what they are prepared for. The relationship between what they have done, and what they are prepared for, can be examined via the use of the ACWR (White, 2017).

2.5.2 Quantifying the acute chronic workload ration (ACWR)

The value of the ACWR is calculated by dividing the acute workload (fatigue) by the chronic workload (fitness) (Gabbett, 2016a). For example, an acute workload of 1 500 AU may be divided by a chronic workload of 1 600 AU, providing an ACWR of 0.94.

$$ACWR = \frac{\textit{Acute Load (fatigue)}}{\textit{Chronic Load (fitness)}}$$

$$ACWR = \frac{1500 \textit{ AU}}{1600 \textit{ AU}}$$

$$ACWR = \mathbf{0.94}$$

Generally, in team sports such as soccer (Malone *et al.*, 2017a) or rugby (Hulin *et al.*, 2014), which have weekly fixtures (e.g., Saturday to Saturday), the acute workload is the TL performed by an athlete in one week, and the chronic workload is the four-week average acute workload (as stated above) (Hulin *et al.*, 2014). Having said this, it is important to note that these periods can be personalised according to the physical demands of the sport, calendar demands associated with that sport, and individual athlete responses based on the practitioner's experience of the athlete's previous response to TL.

The time period of the acute and chronic load was investigated by Carey *et al.* (2017) in order to find the best model fit between the ACWR and soft-tissue injury risk. The study found that a 3:21 day ratio best described non-contact injury

occurrence when utilising moderate speed running (18-24 km/h) to calculate the ACWR. Additionally, findings indicated that the length of the acute window exhibited a strong influence over the ability of the ACWR to inform on injury risk, and indicated that an acute time period between three to six days combined with a chronic time period between 21-28 days would best explain injury risk (Carey *et al.*, 2017). The study concluded that the most suitable choices for the acute and chronic time windows may need to be identified for each sport and team and is specific to athlete's competition and training schedule (Carey *et al.*, 2017). Thus, further research is required to better understand this aspect of the ACWR (White, 2017).

The comparison of the acute workload to the chronic workload as a ratio, is therefore a dynamic representation of a player's preparedness (Malone *et al.*, 2017a). The ratio allows practitioners to consider the TL the athlete has performed recently (within the last training week) relative to the TL the athlete has prepared for (within the last four weeks).

2.5.2.1 The acute workload

Typically, this is the workload performed by an athlete in one week (seven days) (Hulin *et al.*, 2014). This value contains both training and match load information over this seven-day period. It is this value that is represented as the fatigue aspect of the ACWR.

For example, a common method for calculating workload is by multiplying the RPE by session duration. Thus, if an athlete reported an RPE of four and trained for 200 minutes, the athlete's workload for the day would be 800 AU (Foster *et al.*, 2001).

$$\textit{Workload (AU)} = \textit{Intensity(RPE)} \times \textit{Volume (Duration (min.))}$$

$$\textit{Workload (AU)} = 4 \times 200\textit{min}$$

$$\textit{Workload (AU)} = 800$$

If the athlete trained twice in one day (e.g., a field session and a gym session), then the workload for both of these sessions would be added together to calculate the acute workload for that given day (e.g., $800 + 200 = 1\,000$ AU).

This process would need to be replicated for each athlete, and for every training and match day. The final acute workload value and interpretation of the data will vary according to the ACWR model that the practitioner utilises (e.g., The Rolling Average Model (RA) or the Exponentially Weight Moving Average Model (EWMA)) and the acute and chronic time period utilised (described below) (White, 2017).

2.5.2.2 The chronic workload

The chronic workload is typically the four week (28 day) average acute workload (Hulin *et al.*, 2014). This value is important as it provides a clear indication of what an athlete has done leading up to the present training or match day. Therefore, it is commonly viewed as an indication of an athlete's fitness. For example, let's suggest an athlete had a weekly average (acute) workload consisting of the following:

Week 1 = 1 600 AU

Week 2 = 1 400 AU

Week 3 = 1 700 AU

Week 4 = 1 900 AU

In this case, the four-week chronic workload value would be the average of these four workloads.

$$\text{Chronic Workload} = \frac{\sum(\text{Week 1} - 4)}{4}$$

$$\text{Chronic Workload} = \frac{1\,600 + 1\,400 + 1\,700 + 1\,900}{4}$$

$$\text{Chronic Workload} = 1650 \text{ AU}$$

This is a simple example of what the four week chronic workload represents, but it is important to note that a three week (21 day) chronic workload value is also commonly used (Carey *et al.*, 2017). Similarly, to the acute workload, both the exact calculation of the chronic workload, and its dynamic day-to-day and week-to-week value, will depend on the type of ACWR model that is being utilised by the practitioner (e.g., RA or EWMA model) and the time period being utilised, as mentioned above.

2.5.2.3 The two acute chronic workload ratios (ACWR) models

There are two primary models for calculating the ACWR, these are:

- i. The Rolling Average Model (RA)
- ii. The Exponentially Weighted Moving Average Model (EWMA)

The main difference between these two models is the method of calculating the ACWR. One method uses a linear approach and the other a non-linear exponential approach.

- i. The Rolling Average Model (RA)

The RA model uses absolute (i.e., total) workload performed in one week (acute workload) relative to the four week chronic workload (i.e., the four week average acute workload). Prior studies have defined a training week as one which starts on a Monday and ends on a Sunday, consisting of seven days and have calculated the ACWR as a weekly value per athlete (Hulin *et al.*, 2014; Hulin *et al.*, 2016a; Hulin *et al.*, 2016b; Bowen *et al.*, 2017).

The daily calculation of the ACWR was investigated by Carey *et al.* (2017) in order to examine different time periods of the acute and chronic workload calculations. The formula utilised:

$$r_i = \sum_{j=i-a}^{i-1} \frac{W_j}{a} / \sum_{j=i-c}^{i-1} \frac{W_j}{c}$$

The workload of an athlete on day 'i' is 'w_i', the ACWR for that day is 'r_i', 'a' and 'c' represent the time windows (in days) over which the acute and chronic workloads are calculated. The formula calculates the ACWR each day by taking the average daily workload of the previous 'a' days (i.e., not including what was done on that day) and dividing it by the average daily load of the previous 'c' days (Banister *et al.*, 1975; Carey *et al.*, 2017). This formula allows the practitioner freedom of choice in the parameters 'a' and 'c' as well as the workload variable, 'w'.

The RA model suggests that each workload in an acute and chronic period is equal. Thus, it considers the relationship between TL and adaptation as linear, and therefore, all workload in a given time period is seen as equivalent. A possible limitation of this model is that there is failure to accurately account for any decay in fitness, nor does it accurately represent variations in the manner in which TLs are accumulated. A potential solution to these limitations of the RA model may lie with the EWMA model (Hunter, 1986; Williams *et al.*, 2017).

ii. The Exponentially Weighted Moving Average Model (EWMA)

This model utilises the EWMA method to calculate acute and chronic workloads (Hunter, 1986). It assigns a decreasing weighting for each older value, thus placing a greater emphasis on the most recent workload an athlete has performed (Murray *et al.*, 2017). The equation for the calculation of load using the EWMA can be seen below:

$$EWMA_{today} = Load_{today} \times \lambda_a + ((1 - \lambda_a) \times EWMA_{yesterday})$$

λ_a is a value between 0 and 1 which represents the degree of decay. A higher value discounts older observations at a faster rate. The specific value of λ_a is given by:

$$\lambda_a = 2/(N + 1)$$

'N' is the time decay constant chosen by the practitioner which is represented by the number of days which make up the acute and chronic time periods. Thus, if an acute period of seven days and a chronic period of 28 days was chosen, the decay constant values would be:

$$\text{Acute Decay Constant} = 2/(7 + 1)$$

$$\text{Acute Decay Constant} = \mathbf{0.25}$$

$$\text{Chronic Decay Constant} = 2/(28 + 1)$$

$$\text{Chronic Decay Constant} = \mathbf{0.0689}$$

This model was specifically designed to account for the decaying nature of fitness, and the non-linear nature of injury occurrence and workload (Hawley, 2002). Additionally, it better represents variations in the manner in which loads are accumulated (Williams *et al.*, 2017). In order to better visualise the differences between the RA model and the EWMA model, a graphical representation of an athlete's TL and ACWR is provided below in Figure 2.3.

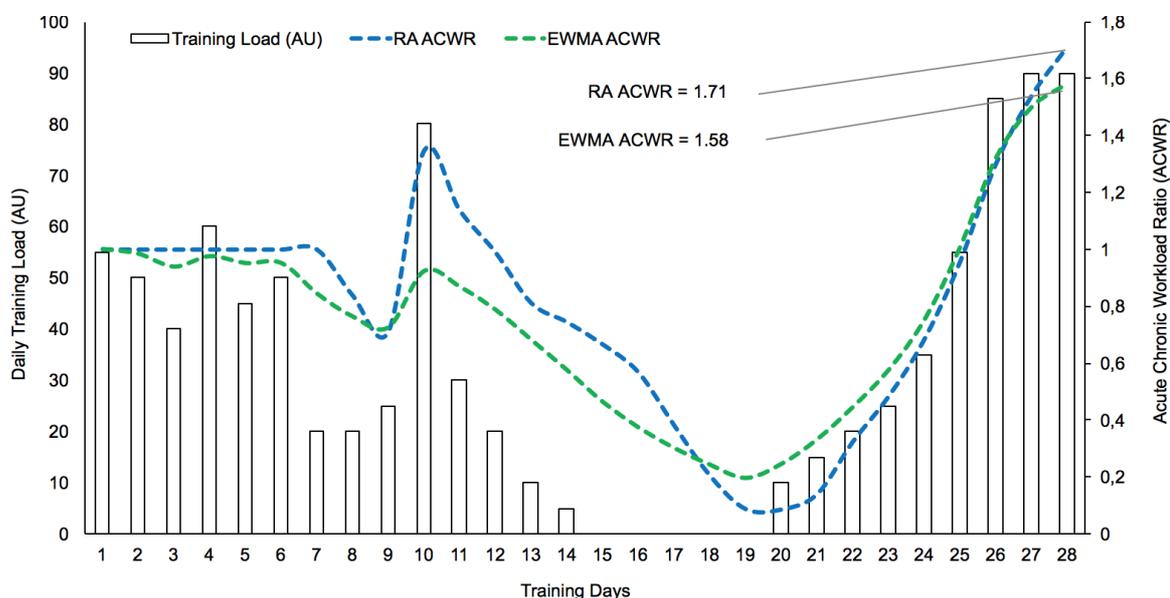


Figure 2.3 The relationship between the RA ACWR and the EWMA ACWR.

According to the RA model, if an athlete trained at the TL depicted above, which sees the athlete cease training from day 15 until day 19 and then resume training on day 20 at a progressively increasing TL until day 28, the ACWR calculation on day 28 will be as follows:

$$\text{Acute Load} = 400 \text{ AU}$$

$$\text{Chronic Load} = 234 \text{ AU}$$

$$\text{ACWR} = \frac{400}{234} = \mathbf{1.71}$$

However, because the EWMA model places greater emphasis on the most recent workload and accounts for the decaying nature of fitness (rather than a steep drop off in fitness, as depicted by the RA model), it would calculate the same athlete's ACWR to be 1.58 on day 28. The EWMA model does this by applying an exponentially weighted formula (stated in above section) to calculate the acute load and the chronic loads. This method of calculating the ACWR could provide a more realistic ACWR value and potentially, a more accurate, injury sensitive, snapshot of an athlete's preparedness (Murray *et al.*, 2017).

2.5.2.4 Limitations and advantages of the models

The ACWR is typically calculated using one of the two primary models (RA and the EWMA), as discussed above. The question that remains is, which model is superior? The RA method of calculating the ACWR is evidence-based (Drew & Finch, 2016; Gabbett, 2016a) and is strongly supported by available literature (Blanch & Gabbett, 2016). However, there are several concerns and limitations around the RA model. Firstly, using averages overlooks variations in the set period of time and hides overall TL patterns (Menaspà, 2017). The second limitation of using averages to calculate the ACWR is that they do not consider when a given training stimulus happened within the acute or chronic time period. This may be problematic, because the effect of a training stimulus declines over time (Hawley, 2002), and the use of averages neglects this fundamental aspect (Menaspà, 2017).

Thus, despite the proven association between RA ACWR and injury risk (Hulin *et al.*, 2014), it is hypothesised that a non-linear TL model which accounts for the non-linear relationship between TL and injury, may be better suited to identifying injury risk. This was the rationale for proposing the EWMA model.

Williams *et al.* (2017) argued that the EWMA model places greater emphasis on workloads towards the end of the calculation cycle thus, better accounting for the natural decay in fitness over time. Secondly, the EWMA is reported to be more sensitive to day-to-day changes in workload and will allow practitioners to better detect where an athlete is positioned on the ACWR spectrum. This will allow practitioners to better prevent athletes from entering into the so-called 'danger zone' (Gabbett, 2016a). Additionally, Murray *et al.* (2017) investigated the EWMA model in AF and found that a high EWMA ACWR was significantly associated with an increase in injury risk and concluded the study by stating that, "The EWMA model is more sensitive to detect increases in injury risk at higher ACWR ranges during the preseason and in-season periods" and that, "the EWMA model may be better suited to modelling workloads and injury risk than the RA ACWR model" (p. 6).

Despite the proposed advantages of the EWMA model, its use may undervalue fundamental concepts of training. These training concepts include daily variation and reductions in TL to either prevent spikes in monotony and strain, manage fatigue, prevent overtraining, and/or induce taper prior to competition (Foster, 1998; Gabbett *et al.*, 2016b). Athletes may benefit from these practices through reduced levels of accumulative fatigue which will allow for recovery, positive physiological adaptation, improved performance and increased fitness (Mujika *et al.*, 2004). These actions may actually protect against injury (Gabbett, 2016a). Thus, more studies are required to determine which model is superior between the RA and EWMA model.

In summary, both models show merit. However, the RA model is the only model which is evidence-based (Drew & Finch, 2016; Gabbett, 2016a) and is strongly supported by available literature (Blanch & Gabbett, 2016). The EWMA seems to address some of the issues pertaining to the RA model, however, more research is required to determine its validity. It was suggested by Sampson *et al.* (2017), that an analysis of data bases across multiple sports applying a number of models to the same data would be required in order to determine which model performs best and would be more useful to practitioners.

2.5.3 What can be used to calculate the acute chronic workload ratio (ACWR)?

Sport scientists and medical practitioners can use the ACWR to monitor and track a variety of different TL metrics. Practitioners typically obtain measures of external TL (the mechanical load placed on an athlete) in isolation, or in combination with a measure of internal TL (the physiological or psychological response to the imposed demands) (Huxley *et al.*, 2013; Soligard *et al.*, 2016).

2.5.3.1 The external load

External load is the external stimulus applied to the athlete (Gabbett, 2004). It is the objectively measurable physical work performed during training and/or competition. A common way of measuring external load is using wearable technology. Examples of external load metrics include:

- The number of high-speed running meters
- Number of accelerations
- Tonnage measured in kg.

2.5.3.2 The internal load

Internal load is the individual physiological and/or psychological response to external loads, combined with daily life stressors and other environmental and biological factors (Huxley *et al.*, 2014). It includes objective measures such as HR, as well as subjective measurements such as RPE. Examples of internal load metrics include:

- HR
- RPE
- Creatine kinase measures
- Blood [lactate].

It is important for the practitioner to understand that identical external TL could elicit considerably different internal TL in two athletes. For example, if two random athletes were both asked to run five km, their external TL would be identical (i.e., 5000 m) however, their internal perception of the imposed external TL would vary according to any physiological and/or psychological differences or make up of the

athletes. These differences mean that the training stimulus (i.e., external load prescribed) may be appropriate for one athlete, but inappropriate for another (either too high or too low). Thus, monitoring of TL should be done on an individual basis when possible, and focus on the metrics that will provide the best insight for an individual or a team (White, 2017).

2.5.4 The acute chronic workload ratio (ACWR) and research findings

A variety of studies have investigated the ACWR using both external measures (Hulin *et al.*, 2016; Bowen *et al.*, 2017) and internal measures (Malone *et al.*, 2017a) to calculate the ACWR and have identified particular relationships and trends.

2.5.4.1 The acute chronic workload ratio (ACWR) and injury risk

As stated previously, comparing the acute TL to the chronic TL as a ratio provides a snapshot of the athlete's preparedness. If the acute TL is low (i.e., the athlete is experiencing minimal fatigue) and the chronic TL is high (i.e., the athlete has developed fitness), then the athlete will be in a well-prepared state (Gabbett, 2016a). In this scenario, the ACWR will approximate 1.00. Inversely, if the acute TL is high (i.e., high levels of fatigue) and the chronic TL is low (i.e., low fitness levels), then the athlete will be in a more fatigued state. In this case, the ACWR will exceed 1.00 (Gabbett, 2016a).

Studies have investigated this ratio in a variety of sports, ranging from AF (Murray *et al.*, 2016; Stares *et al.*, 2016; Carey *et al.*, 2017; Colby *et al.*, 2017) and rugby league (Hulin *et al.*, 2016a; Hulin *et al.*, 2016b), to soccer (Bowen *et al.*, 2017; Jaspers *et al.*, 2017; Malone *et al.*, 2017a) and Gaelic games (Malone *et al.*, 2017b). The majority of these studies found the same trends and relationships in terms of the ACWR and subsequent injury risk. This is represented in the figure below (Figure 2.4).

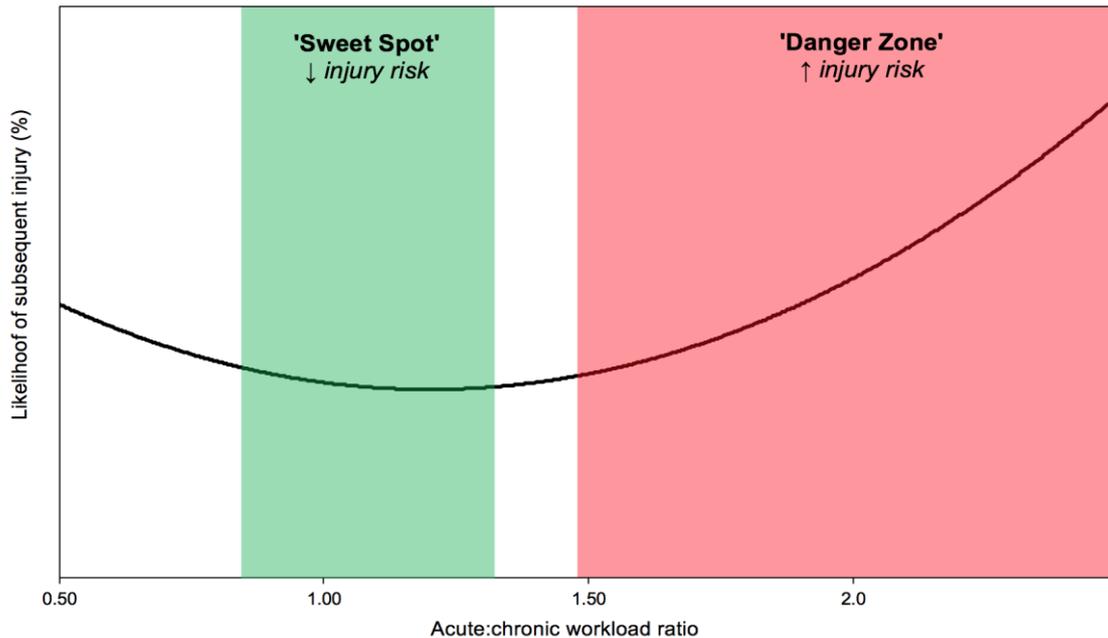


Figure 2.4 The U-Shape relationship between ACWR and injury risk in the subsequent week (%), adapted from Gabbett (2016a).

Practically, this means that the ACWR can be monitored either every day, or on a weekly basis, for each athlete. The actual value of the ratio will have a practical significance, and with careful planning and alteration it could help to reduce the risk of injury. The ACWR value and its various qualitative interpretations are listed below:

- **< 0.80** (Under training and higher relative injury risk)
- **0.80-1.35** (Optimal workload and lowest relative injury risk.)
- **1.35-1.50** (Over training and increasing relative injury risk)
- **1.50** (The danger zone and highest relative injury risk).

It is important to note that these values will not apply to every athlete in every sport. An athlete's prior training history, development, injury record, and level of participation will have a major influence on their TL tolerance and subsequent injury risk. Researchers and practitioners have carried out extensive research in a variety of different sporting codes in order to clarify the relationship between the ACWR and injury risk (i.e., to identify sport-specific sweet spots or danger zones). The summary and findings of these studies can be seen below in Table 2.2.

Table 2.2 ACWR and injury risk.

Sport	Authors	Training Load Metric Measured	ACWR Zone Identified	Sport	Authors	Training Load Metric Measured	ACWR Zone Identified
AF	Stares et al. (2017)	Internal (sRPE) & External (GPS - distance and sprint distance)	High risk categories found were when the ACWR was low (<0.6) or high (>1.5)	AF	Colby et al. (2017)	Internal (sRPE & subjective wellness questionnaire) & External (distance & sprint distance)	High risk categories found when a low chronic load was coupled with a low ACWR of (<0.80) or high (>1.20-1.40)
AF	Murray et al. (2016)	External (GPS - total distance, low speed distance, moderate speed distance, high speed distance, very high speed distance and player load)	An ACWR of >2.0 was coupled with greater injury risks for all workload variables	Basketball	Weiss et al. (2017)	Internal (sRPE)	A 'sweet spot' of 1.0-1.49 was identified. Risk increased with ratios <0.99 and >1.50
AF	Carey et al. (2017)	Internal (sRPE) & External (GPS - distance, player load, distance-load, HSR & MSR)	A 'sweet spot' of 0.8-1.0 was identified. Risk increased with ratios on either side of this region	Cricket	Warren et al. (2018)	External (Balls bowled)	High injury risk was identified in ACWR ranges of >1.09

Abbreviations: ACWR - acute chronic workload ratio, AF - Australian football, GPS - Global Positioning System, sRPE - session rating of perceived exertion, HSR - high speed running, MSR - moderate speed running.

Table 2.2 ACWR and injury risk.

Sport	Authors	Training Load Metric Measured	ACWR Zone Identified	Sport	Authors	Training Load Metric Measured	ACWR Zone Identified
Gaelic Football	Malone et al. (2017)	Internal (sRPE)	A high ACWR (>2.0) was associated with an increased injury risk. A safe zone of between 1.35-1.50 was also identified	Soccer	Malone et al. (2016)	Internal (sRPE)	A 'sweet spot' of 1.0-1.25 was identified which offered a protective effect
Rugby	Hulin et al. (2016a)	External (GPS - distance)	High (1.2-1.6) and very high (>1.6) ACWR combined with short recovery between matches increased injury risk	Soccer	Jaspers et al. (2017)	Internal (sRPE) & External (GPS - total distance, HSR, no. of acc efforts & no. of decell efforts)	A high ACWR (>1.18) for HSR resulted in a higher injury risk. A 'sweet spot' of between 0.87-1.12 for acc & decell & sRPE was found
Soccer	Bowen et al. (2016)	External (GPS - total distance, HSD, ACC, TL)	A high ACWR (>1.77) was associated with an increased risk of injury				

Abbreviations: ACC - acceleration's, ACWR - acute chronic workload ratio, Decel - deceleration, GPS - Global Positioning System, sRPE - session rating of perceived exertion, HSR - high speed running, MSR - moderate speed running, TL - training load.

2.5.4.2 Week-to-week variation in training load

The process of analysing TL data and calculating ACWR can yield helpful insight into TL progression, particularly as it is a useful tool to view changes in workload over time. Because of this, research has subsequently investigated this relationship and found that excessive and rapid increases in TL are responsible for a large percentage of non-contact soft-tissue injuries (Gabbett, 2004; Hulin *et al.*, 2016b; Soligard *et al.*, 2016; Malone *et al.*, 2017a).

It is, therefore, important to consider how week-to-week changes in TL influence injury risk. In a study on Australian football (AF) players, it was reported that 40% of injuries were associated with a rapid change (>10%) in weekly (i.e., acute) TL compared to the previous week (Piggott, 2008). Therefore, to minimise the risk of injury, practitioners may wish to limit weekly TL increases to less than 10%.

2.5.4.3 High chronic loads and injury protection

The ACWR can not only be used to monitor athletes from day-to-day and week-to-week, but it can also be used during TL planning and periodisation. Evidence suggests that both physically challenging, and accumulated physically hard training (due to appropriately planned training programmes), may protect against injuries (Hulin *et al.*, 2016b). For example, one study found that athletes with high chronic loads (fitness) had better protection against injuries when exposed to high acute TL (Hulin *et al.*, 2014).

From a practical perspective, this means that if practitioners have a good understanding of the load that their athletes are going to experience in competition, they can plan training programmes in order to appropriately prepare them for these events. This may offer a protective effect against injury, and may theoretically lead to greater physical performance and resilience in competition, as well as higher levels of athlete availability (i.e., having more athletes available for training and competition) (Gabbett, 2016a). A summary of research findings regarding week-to-week changes in workload and subsequent injury risk, in addition to the protective effect of high chronic loads, can be seen below in Table 2.3.

Table 2.3 ACWR change in workload and injury risk.

Sport	Authors	Training Load Metric Measured	ACWR Zone Identified	Sport	Authors	Training Load Metric Measured	ACWR Zone Identified
Australian Football	Stares <i>et al.</i> (2017)	Internal (sRPE) & External (GPS - distance and sprint distance)	Injury risk was greatest when the chronic load was low and the ACWR was either low or high	Cricket	Warren <i>et al.</i> (2018)	External (Balls bowled)	Spikes in workload were associated with an increase in injury risk
Australian Football	Murray <i>et al.</i> (2016)	External (GPS - total distance, low speed distance, moderate speed distance, high speed distance, very high speed distance and player load)	The results demonstrate that the abrupt increases in acute workload are significantly related to injury. High chronic workloads offer a protective effect, reducing the risk of injury	Cricket	Hulin <i>et al.</i> (2014)	Internal (sRPE) & External (Balls bowled)	Large increases in acute workload are associated with increased injury risk in elite cricket fast bowlers
Australian Football	Colby <i>et al.</i> (2017)	Internal (sRPE & subjective wellness questionnaire) & External (distance & sprint distance)	Low chronic loads coupled with low or very high ACWR are associated with increased injury risk	Rugby	Hulin <i>et al.</i> (2016a)	External (GPS - distance)	Higher chronic workloads provide protection from spikes in acute workload
Australian Football	Piggott (2008)	Internal (sRPE) & External (GPS - distance and distance run >12 km/h)	42% of illnesses explained by preceding spike in TL, whilst 40% of injuries explained by preceding spike in TL	Rugby	Hulin <i>et al.</i> (2016b)	External (GPS - total distance)	Players with a high chronic workload were more resistant to injury when subjected to training load spikes

2.5.5 Potential limitations of the acute chronic workload ratio (ACWR)

There are several confounding factors that limit the ACWR monitoring method and its use in sport, and while the majority of research points to it being a useful tool, there are several drawbacks and debates.

2.5.5.1 Assessing an athlete's locomotor profile and their relative external load

i. Speed

There are subtle differences between sprint intensity (high vs. very high-speed running) and its relevance with regard to injury risk and prevention (Malone *et al.*, 2017b). Because of these subtle differences the individualisation of high-speed running zones is likely important (Buchheit, 2017). However, the individualisation of speed zones may require the athlete's maximal sprinting speed as a reference, which is usually not readily available and is difficult to simulate outside of match conditions. To solve this problem, practitioners have made use of absolute speed zones (Buchheit, 2017), however, due to the large variation in locomotor profiles between athletes, this method may reduce the sensitivity of the ACWR with respect to high-speed running load (Malone *et al.*, 2017b) and injury risk.

ii. Determination of athlete fitness:

Recent studies have highlighted the importance of fitness, its protective effect, and the workload an athlete can be subjected to without becoming injured (Malone *et al.*, 2017b). In professional soccer, it is rare that athletes are subjected to fitness testing (Buchheit, 2017). It is, therefore, difficult to define which ACWR values may be critical when monitoring a squad of athletes with unknown fitness levels.

In summary, the difficulties in determining an athlete's locomotor profile may limit the sensitivity of the ACWR to injury, thus, limiting the ACWR usefulness in load monitoring.

2.5.5.2 Combining data, international breaks and the off-season

In a sport, such as elite soccer for example, GPS tracking is often utilised during training to quantify the external loads of players, however, on a match day,

camera-based systems are used (Buchheit *et al.*, 2014). The integration of these metrics is not seamless, and the accuracy of measuring high-speed running and acceleration metrics is questionable (Buchheit *et al.*, 2014). This may decrease the sensitivity of ACWR values calculated utilising these metrics, which may limit its usefulness in load monitoring.

Buchheit (2017) reported that within elite clubs, one-third of the squad may contain international athletes, who will need to travel for international duty between eight to 10 days, four to five times each year. These international breaks represent one of the greatest challenges for clubs' sports medicine practitioners who are seeking to keep track of their athletes' match and TL. The challenge arises when the vast majority of national teams' staff use monitoring approaches and systems that differ substantially from those being utilised by an athletes' domestic club.

Similar to the issue raised above, off-season breaks pose their own challenges. Athletes generally return to see family in home towns and countries, or go on holiday for relaxation. Once an athlete has left the club environment there is a complete lack of off-season monitoring. Thus, practitioners can only estimate the physical state the athletes may return in, limiting the sensitivity of monitoring until sufficient chronic loads have been developed during the pre-season period.

In summary, the issues with integrating different monitoring technologies combined with the issues that international breaks and the off-season pose, may limit the sensitivity of the ACWR value to injury risk. Thus, decreasing its usefulness as a monitoring strategy.

2.5.5.3 Mathematical issues with the acute chronic workload ratio (ACWR) calculation

Lolli *et al.* (2017) suggested that the acute load of the ACWR calculation also constitutes a substantial part of the chronic load (Blanch & Gabbett, 2016). This mathematical coupling between the two variables raises the possibility that research findings and current athlete monitoring methods might be compromised by the resulting spurious correlations (Brett, 2004). Lolli *et al.* (2017) concluded

their investigation by stating that a solution may be, to not include the acute load in the calculation of chronic load if the TL-injury relationship, specific to the ACWR is to be examined accurately.

2.6 CONSIDERATIONS FOR CURRENT RESEARCH

Despite the limitations of the ACWR outlined above, recording acute and chronic TL and modelling the ACWR still allow practitioners to determine if athletes are in a state of fitness (i.e., net training recovery, lower than average risk of injury) or fatigue (i.e., net training stress, higher than average risk of injury) (Banister *et al.*, 1975). Additionally, utilising the ACWR allows practitioners to view a snapshot of an athlete's training- and match-load history, thus, allowing competition and training readiness to be gauged more easily. This improved interpretation of readiness could assist to better plan and periodise training, act as a flagging value for injury risk, and subsequently improve performance. The actual value presented by the ACWR has different implications and requires further study in order to determine its usefulness and role with regards to athlete load monitoring in the future (White, 2017).

To date, there is limited research that has investigated the relationship between acute and chronic workloads and the ACWR in elite male soccer players and injury risk. This research study will make use of the weekly RA model to calculate both acute and chronic loads, in addition to the ACWR. The acute time period will be set at seven days (one week), and the chronic time period will be set at 28 days (four weeks). Researchers feel that the time-period chosen to represent the acute and chronic loads is fully validated, despite the recent mathematical issues raised by Lolli *et al.* (2017). More evidence is required in order to discount the current standard practice.

The RA model will be utilised instead of the EWMA model because the RA model is the only model which is evidence-based (Drew & Finch, 2016; Gabbett, 2016a) and is strongly supported by available literature (Blanch & Gabbett, 2016). To the researcher's knowledge, only one study has utilised the EWMA model in team sport (Murray *et al.*, 2017), and it showed that both models had merit with regards to the sample data set analysed. Thus, the researchers feel that in order to best

investigate the ACWR in their chosen sample population, an evidence-based standard practice should be utilised, until the EWMA model has been more appropriately reported on.

In addition to assessing the ACWR, the literature identified that weekly cumulative TL and excessive and rapid increases in TL could be responsible for a large percentage of non-contact soft-tissue injuries (Gabbett, 2004; Hulin *et al.*, 2014; Soligard *et al.*, 2016; Malone *et al.*, 2017a). Therefore, the researchers feel that including these variables in conjunction with the ACWR may assist in identifying any potential relationships.

Chapter Three

Article One: Internally-derived acute:chronic workload ratio is associated with non-contact injury risk in professional soccer players.

This article will be submitted for publication in the *Journal of Science and Medicine in Sport*. The article is herewith included according to the guidelines for authors of this esteemed journal. However, to provide a neat and well-rounded final product for this thesis, the article has been edited to represent a published article as it would appear in this particular journal. This does not imply that the article has been accepted or will be accepted for publication. Subsequently, the referencing style, font, figures and tables used in this chapter may differ from that used in the rest of the chapters of this thesis.

Internally-derived acute:chronic workload ratio is associated with non-contact injury risk in professional soccer players

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ARTICLE INFO	ABSTRACT
<p><i>Keywords:</i> Acute:chronic workload ratio Session rating of perceived exertion Load monitoring Team sport Injury prevention</p>	<p><i>Objectives:</i> This study examined the association between internally-derived workload indicators (1-4 weekly cumulative load and the acute:chronic workload ratio (ACWR)) and injury risk in professional soccer players.</p> <p><i>Design:</i> Prospective cohort study.</p> <p><i>Methods:</i> Data was collected from forty-one professional male soccer players over 1.5 seasons. The internal workload was examined with use of session rating of perceived exertion (sRPE). Cumulative 1-, 2-, 3-, 4-weekly loads and ACWR (1:4) were calculated and split into quintiles; low, moderate-low, moderate, moderate-high and high. Soft-tissue non-contact injuries were included into the analysis to determine their association with training and match loads. Generalised estimation equations (GEE) were applied to analyse the association between specific workload indicators (ACWR and 1-4 weekly cumulative workload) and injury in the subsequent week. Magnitude based inference (MBI) was used to interpret changes in injury risk between the workload zones of statistically significant workload indicators.</p> <p><i>Results:</i> In total, 85 soft-tissue non-contact injuries were recorded. Only the ACWR was significantly associated with injury in the subsequent week. MBI results indicated an increased injury risk for moderate-low to high ACWR compared to a low ACWR workload zone. However, when a moderate-high ACWR zone was utilised as the reference group, only moderate-low and high ACWR increased injury risk.</p> <p><i>Conclusion:</i> Findings demonstrate that internally-derived ACWR is significantly associated with injury occurrence in the subsequent week. Specifically, that acute training load deviations; de-loads and/or 'spikes' relative to a players' chronic load foundation, increases injury risk compared to a moderate-high ACWR from 1.02 to 1.14.</p>

Introduction

Professional soccer is physiologically demanding and requires diverse athletic capabilities including aerobic endurance, explosive power and repeated sprint ability.^{1,2} The high physical demands of the sport, extended competition calendars and limited rest, may collectively contribute to the high number of injuries sustained by professional players.³ On average, a player sustains two injuries per season, resulting in an absence of 37 days in a 300-day season.⁴ An extended injury absence may be detrimental to team success and result in financial ramifications, particularly in professional soccer settings.³ Subsequently, there has been an increased interest in monitoring

training and match loads to prevent injury and improve performance.⁵

Workloads are generally quantified in terms of external and internal loads.⁶ The external load refers to the mechanical demands of the sport and can be tracked by use of global positioning systems (GPS).⁵ The internal load refers to the physiological and/or psychological response to the external load, and can be determined using session rating of perceived exertion (sRPE).⁵ This method is particularly useful for monitoring the internal workloads of soccer players.⁷ The relationship between internal load and injury risk has been determined in a variety of elite team

sports such as Gaelic football,⁸ cricket,⁹ rugby union¹⁰ and soccer.^{7,11,12}

Using sRPE measures, researchers initially considered the workload-injury relationship as linear in nature; the more load a player was subjected to, the higher their injury risk.¹³ However, later studies identified high injury risk conditions for rapid increases in absolute acute training load (TL),⁹ high accumulated TL,¹⁰ and low accumulated TL.¹⁴ Despite these findings, lower injury risk was identified for intermediate TL in rugby union players¹⁰. These findings suggest that the workload-injury relationship is non-linear and rugby union¹⁰ and cricket⁹ studies have reported a u-shaped relationship. This suggests that an optimal training and match load range may exist for injury prevention.

To assess the relative effect of absolute and accumulative TL on injury risk, workload-injury investigations have recently started to utilise the acute:chronic workload ratio (ACWR).⁹ This TL index considers a player's absolute workload performed in 1-week (acute load) relative to a 4-week chronic load (average 4-week acute load).⁹ The comparison of the acute load to the chronic load is based on the assumption that performance can be estimated from the difference between fatigue (acute load) and fitness (chronic load).¹⁵

Methods

Forty-one professional male soccer players (mean \pm SD age: 24.5 \pm 3.6 years; stature: 176.3 \pm 6.6 cm; body mass: 74.4 \pm 7.9 kg) from the first team of a club competing in division one in South Africa (Premier Soccer League) participated. Data was collected over one and a half seasons (2016-2018), including pre-season and in-season. The study was approved by the University Research Ethics Committee for Humanoria (SPORT-2017-0162-121), in line with the Helsinki declaration. Written informed consent was obtained from all participants.

Workload data was captured utilising the previously validated modified Borg rating of perceived exertion (RPE) CR-10 scale.¹⁸ All participants were familiar with the modified Borg CR-10 scale before the start of the study, and a graphic representation of the scale depicting the score and word association was available throughout. This method was utilised to prevent perceived bias when interpreting a training session's intensity and/or lack of understanding.¹⁸ In addition, to ensure that the perceived intensity

Therefore, an inappropriately prescribed TL which is too high or too low may induce excessive fatigue, (i.e. limiting performance and increasing injury risk) or prevent improvements in fitness (i.e. limiting adaptation and increasing injury risk).⁵ The ratio ultimately considers the TL performed relative to what a player is prepared for, thus providing a quantitative representation of a player's physical preparedness and injury risk by objectively measuring the magnitude of the fitness-fatigue relationship.^{11,16}

The use of ACWR showed that higher chronic loads may protect against injury, but that both acute workload spikes and de-loads increase injury risk in the subsequent week.^{9,14,17} These findings suggest that the workload-injury relationship is non-linear, and that large variations in TL prescription is potentially a significant risk factor for injury. Despite this evidence, few studies have been conducted in professional soccer to assess the association between internal workload and injury risk by means of the ACWR. Therefore, the current study aimed to determine the association between internally-derived (sRPE) workload and non-contact injury risk through the use of cumulative workload measures and the ACWR.

would reflect the session as a whole rather than the final exercise or drill, RPE data was collected post cool-down.¹⁹ The session rating of perceived exertion (sRPE) for each player was determined by multiplying their respective RPE score with their respective session's duration in minutes.^{19,20}

Injury data collection procedures were in line with the consensus statement for soccer injury studies, and all injuries were diagnosed and recorded by members of the medical staff.²¹ Injuries were diagnosed by location, type, and mechanism. Only time-loss, soft-tissue non-contact injuries (hereafter referred to as non-contact injuries) were included in the analysis due to their association with TL.⁷ Injury incidence was calculated by dividing the number of injuries by exposure time and reported as rate per 1 000 training and match hours.²¹

Workload data was grouped into weekly blocks from Monday to Sunday. Cumulative 1-, 2-, 3-, and 4-weekly loads and the weekly ACWR were calculated. Cumulative loads were calculated as the sum of the daily load of the respective

week/week(s).⁹ The weekly ACWR was calculated by dividing the current week's cumulative load by the 4-week rolling average.⁹ Calculated TL data was excluded from the analysis if a time-loss contact injury occurred, players were away with national teams, or players were completing rehabilitation and did not complete team training sessions for any given week. Less than 5% (468 individual sessions from a total of 11 214) of the data was excluded from the analysis based on the exclusion criteria. The data exclusion method was utilised to accurately determine the relationship between the ACWR and time-loss, soft-tissue non-contact injury. Workload data was divided into quintiles to assess injury risk in different zones and to determine the nature, i.e. trend or shape, of the workload-injury relationship. Injury likelihood (percentage) was determined by calculating the frequency of injuries sustained versus the total frequency (exposure) in each workload zone, and reported as the zone, accompanied with injury likelihood percentage (%) (e.g. zone; likelihood (%)). Generalized estimating equations (GEE) were used to model the univariate association between each workload variable and non-contact injury in the subsequent week.¹⁰ The model was set for a

binary distribution (1 for injured and 0 for non-injured) and all load variables were modeled independently as predictor variables. GEE analysis was used as it takes into account the correlated nature of repeated measures data, which makes it superior to traditional logistic regression methods.¹² Workload zones were labeled as: low, moderate-low, moderate, moderate-high and high. Odds ratios (OR) and 95% confidence intervals (CI) were calculated to determine which load variables increased or decreased injury risk. Statistical significance was set at $p < 0.05$. Workload variables that reached statistical significance in the GEE analysis were investigated further using magnitude-based inference (MBI). MBI was used to determine the clinical relevance of any significant variable and to interpret the difference in risk between zones when compared to the reference group.²² Effects were reported using the following scale: 0.0-0.5%: most unlikely; 0.5-2.5%: very unlikely; 2.5-25.0%: unlikely; 25.0-75.0%: possible; 75.0-97.5%: likely; 97.5-99.5%: very likely and $> 99.5\%$: most likely.²³ Clinical relevance was reached when the probability that the true effect was either harmful or beneficial was $\geq 75.0\%$.

Results

A total of 11 214 individual sRPE measures from 1 702 individual training weeks were included in the analysis. In total, 85 non-contact injuries were sustained with an injury incidence of 5.40 injuries per 1 000 training and match hours.

The likelihood of injury in the subsequent week using the ACWR, 1-, 2-, 3- and 4-weekly cumulative loads are shown in Fig. 1. All five workload variables displayed a non-linear sigmoidal (s-shaped) relationship with non-contact injury in the subsequent week. The lowest likelihood of injury for the ACWR was observed at a low (<0.77 ; 1.9%) workload, while a moderate-low (0.77-0.89; 8.7%) and high (>1.14 ; 6.7%) ACWR displayed the highest injury likelihood. The lowest likelihood of injury for 1-weekly cumulative load was observed at a

moderate-low workload (1480-1837 AU; 3.7%), while a moderate (1837-2194 AU; 7.1%) and high (≥ 2551 AU; 8.0%) workload displayed the highest injury likelihood. The lowest likelihood of injury for 2-weekly cumulative load was observed at a moderate-low workload (3104-3671 AU; 3.8%), while a high (>4804 AU; 7.7%) workload displayed the highest injury. The lowest likelihood of injury for 3-weekly cumulative load was observed at a moderate-low workload (4751-5540 AU; 4.3%), while a high (>7119 AU; 7.3%) workload displayed the highest injury likelihood. The lowest likelihood of injury for 4-weekly cumulative load was observed at a moderate-low workload (6328-7301 AU; 4.2%), while a high (>9248 AU; 7.4%) workload displayed the highest injury likelihood.

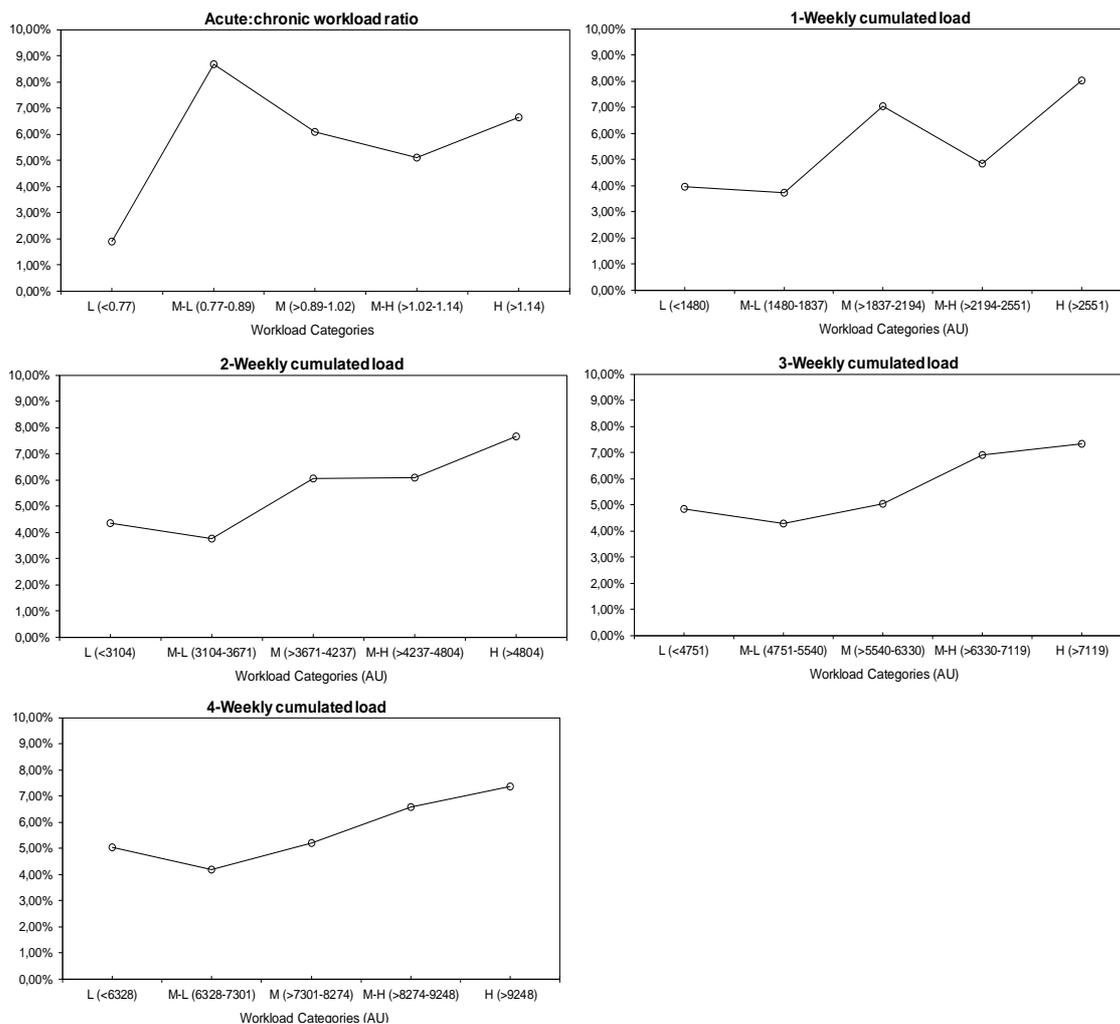


Fig. 1. The likelihood of injury (%) for the ACWR, 1-, 2-, 3- and 4-weekly cumulative workload (in the subsequent week).

Table 1

GEE model effects displaying the association between workload variables and non-contact injury in the subsequent week.

Workload Variables	p-Value
ACWR	0.03*
1-Weekly cumulative load (AU)	0.18
2-Weekly cumulative load (AU)	0.56
3-Weekly cumulative load (AU)	0.99
4-Weekly cumulative load (AU)	0.91

Significant associations appear in bold. Significant p-values marked in bold with * when, $p < 0.05$.

The model effects for the GEE analysis for each of the five workload variables is displayed in Table 1. Only the ACWR yielded a statistically significant association with non-contact injury in the subsequent week (Table 1). Figs. 2a-b. represents the MBI analysis findings. Using the ACWR zone of <0.77 as a reference group (Fig. 2a), most likely harmful effects were observed for

a moderate-low ACWR (0.77-0.89; OR: 5.28, 95% CI: 1.96-14.21) while very likely harmful effects were observed for moderate to high ACWR zones (Moderate: >0.89-1.02; OR: 4.14, 95% CI: 1.40-12.18. Moderate-high: >1.02-1.14; OR: 3.58, 95% CI: 1.22-10.49. High: >1.14; OR: 4.46, 95% CI: 1.43-13.90). Using the ACWR zone of 1.02 to 1.14 as a reference group (Fig. 2b), most

likely beneficial effects were observed for a low ACWR (<0.77; OR: 0.29, 95% CI: 0.14-0.61). A most likely harmful effect was found for a moderate-low ACWR (0.77-0.89; OR: 1.67, 95%

CI: 1.23-2.27) and a likely harmful effect was observed for a high ACWR (>1.14; OR: 1.26, 95% CI: 1.06-1.50).

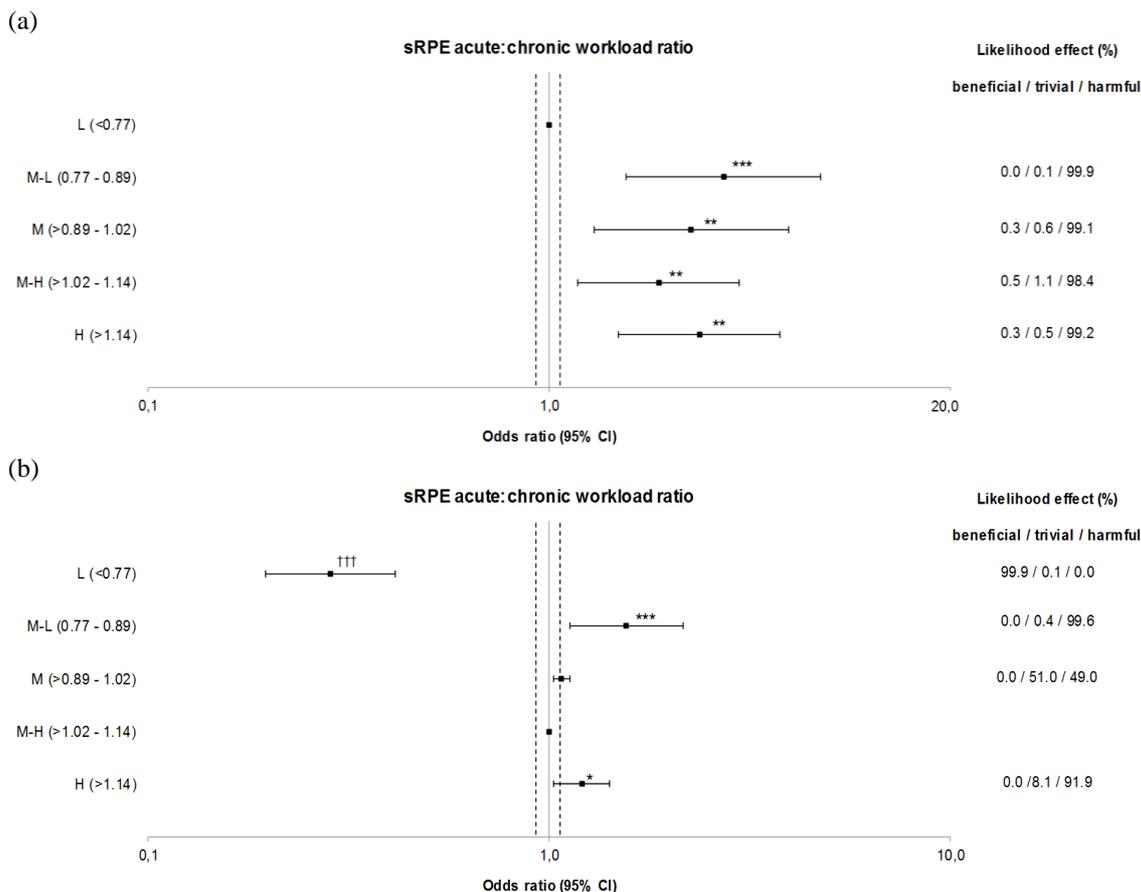


Fig. 2a-b. Injury risk of sRPE for ACWR at moderate-low to high workloads compared to low loads (reference group; a) and injury risk of sRPE for ACWR at low to high workloads compared to moderate-high workloads (reference group; b). Smallest worthwhile changes in injury risk are displayed as dotted lines. Likelihood of effects are shown as percentages. * = likely harmful, ** = very likely harmful, *** = most likely harmful, † = likely beneficial, †† = very likely beneficial and ††† = most likely beneficial.

Discussion

The aim of this study was to determine the association between internal workload and non-contact injury risk among professional soccer players. The ACWR was significantly associated with non-contact injury, while none of the other workload variables showed an association (Table 1). Players who were exposed to an ACWR greater than 0.77 experienced harmful effects with an increased risk of injury in the subsequent week (Fig. 2a) when the lowest workload zone was utilised as a reference group. When a more practical ACWR (from a training-performance perspective) between 1.02 to 1.14 was utilised as the reference group, moderate-low and high ACWR increased injury risk, while a low ACWR

displayed beneficial effects for players in the subsequent week (Fig. 2b). These findings demonstrate the association between internally-derived workload and non-contact injury risk, specifically that transiently elevated or reduced acute workloads increase the likelihood of injury compared to a moderate-high ACWR.

Previous studies have reported relationships between inappropriate TL, either too high (overload), or too low (underload) and increased injury risk.⁵ The results from this study add to this TL monitoring literature by reiterating the association between internally-derived ACWR and non-contact injury in professional soccer.^{7,11,12} The ACWR is based on Banister et al¹⁵ fitness-fatigue model, in that TL provides both positive

(improved fitness) and negative (induced fatigue) effects for exposed players. This assumption allows for the quantification of fitness (i.e. chronic load) and fatigue (i.e. acute load), and previous investigation suggest that injury risk increased when the acute load (fatigue) outweighs the chronic load (fitness).⁹ Our findings reflect this relationship, as players experienced significantly increased likelihood of injury in the subsequent week when exposed to moderate-low to high ACWR compared to a low ACWR of <0.77. This outcome makes sense from a practical point of view, because players with an ACWR greater than 0.77 are exposed to higher acute loads (fatigue) relative to their chronic load foundation (fitness) and are training at a relatively greater acute load volume compared to players with an ACWR of less than 0.77. Therefore, these players are progressively more likely to sustain an injury. However, from a practical training performance perspective, an ACWR of less than 0.77 does not represent a realistic workload index to maintain and/or improve fitness, thus further consideration should be taken before interpreting these results.

Morton²⁴ suggested that the ideal training stimulus is one, which maximises performance potential by striking an appropriate balance between training, competition and recovery. This training stimulus would require an acute TL at, or marginally larger than a player's chronic load foundation, and represent an ACWR of greater than 1.00, but not too high as to constitute overtraining. The low ACWR (<0.77) which was utilised as the initial reference, does not represent a realistic week-in week-out workload index for a professional athlete, as it fails to provide a practical workload index that would elicit fitness maintenance or training super-compensation. Therefore, taking into account the need for an appropriate stimulus to maintain fitness and improve performance, we used the moderate-high ACWR zone of 1.02 to 1.14 as the reference group. This ACWR zone represents a workload index with the lowest likelihood of injury relative to more 'realistic' workloads (Fig. 1), and is one which provides an appropriate training stimulus to maintain the chronic load foundation, while limiting the negative consequences of fatigue. Interestingly, previous studies in professional soccer indicated a training 'sweet spot' at an ACWR between 1.00 to 1.25¹¹ and 0.85 to 1.12,¹² which provided the lowest relative likelihood of injury for the subsequent week. These previously

reported training sweets spots coincide with the selected moderate-high ACWR (1.02-1.14) reference group. Using the moderate-high ACWR zone allows for the comparison of injury risk in the subsequent week for professional soccer players, with more realistic and practical variations in acute TL.

In agreement with previous research, high 1-weekly (acute) loads exhibited the highest likelihood of injury in the subsequent week.⁹ This may explain why a likely harmful effect was associated with a high ACWR of >1.14. A workload index of this magnitude represents an acute TL (fatigue) greater than the exposed players chronic load foundation (fitness), increasing the risk of injury. The increase in injury risk under these circumstances is referred to as an acute TL 'spike' and research suggests that acute spikes in TL increase the risk of injury.^{8,9,25} Inversely, a moderate-low ACWR from 0.77 to 0.89, which represented an acute de-load in TL, exhibited a most likely harmful effect for exposed players in the subsequent week. Similar findings were identified in Australian football, in which an acute de-load in TL was suggested as an additional risk factor for injury as a result of the lowering of the chronic load foundation.¹⁴ This process results in a state of under-preparedness and should be considered a major injury risk factor because the exposed player is not adequately prepared for the physical demands of competition, resulting in increased susceptibility to an acute TL spike and subsequent injury.^{14,25}

The relatively reduced injury likelihood observed at a moderate-high ACWR (compared to moderate-low, moderate and high) and the increased injury likelihood accompanied by transiently elevated or reduced acute workloads, is indicative of a non-uniform ACWR-injury relationship. This relationship implies that players who train enough to maintain and improve their chronic load foundation, while avoiding acute 'spikes' may reduce their likelihood of injury in the subsequent week. These observations are in agreement with previous studies which highlighted a reduced injury risk for players who: avoided acute TL spikes, maintained a solid chronic load foundation (fitness) and, maintained a moderate ACWR.^{5,11,12} The implication of these findings suggests that practitioners and coaches should prescribe TL which are high enough to maintain and improve fitness, but not too high that

it induces fatigue or too low as to result in under-preparedness.

Several limitations should be acknowledged in this study. There are limitations for use of the ACWR in professional sport, namely during international duty and off-season periods, in which time workload data is often not collected.²⁶ Therefore, this data was excluded from the analysis. There are many factors which impact on injury risk (e.g. previous injury, fatigue and age etc.), however, only sRPE derived workload was accounted for in the current analysis.²⁷ Additionally, whilst the sRPE method is an acceptable and valid method for quantifying TL in team sports, GPS-derived measures may provide additional important insight into the relationship between workload and injury risk.^{11,17} Finally, as suggested by Malone et al,¹¹ as with any analysis, the model is best suited to the population from which it was derived.

Conclusions

In conclusion, our findings demonstrate that internally-derived sRPE ACWR is associated with non-contact injury risk in professional soccer players. Additionally, a lack of association was identified between any one cumulative load measure and injury risk, which suggests that by quantifying what a player has done, relative to what they are prepared for, in the form of the ACWR, may assist practitioners in identification of injury risk conditions. Players who were exposed to high and moderate-low ACWR zones experienced increased injury risk compared to those exposed to a moderate-high ACWR zone. This emphasises that the workload-injury relationship is non-linear in nature and that by quantifying the magnitude of the fitness-fatigue relationship, practitioners can limit subsequent injury risk by avoiding acute spikes and de-loads in TL. This highlights the challenge with regard to implementing the ideal training stimulus to maintain and improve performance whilst decreasing the risk of injury, further emphasizing the need to monitor TL closely in order to optimize the training process, by reducing injury risk and improving performance in professional soccer.

Practical applications

- The non-invasive, cost effective and easy to administer sRPE method is useful to quantify and monitor internal workload utilising the

ACWR to interpret injury risk in professional soccer.

- The ACWR may represent a more practical and time efficient workload component for practitioners to monitor, rather than cumulative workload measures as it takes into account what an athlete has done relative to what they are prepared for.
- A moderate-high ACWR of 1.02 to 1.14 may offer the lowest 'relative' injury risk for players than when compared to a high and moderate-high ACWR zone. Therefore, practitioners should utilize this training load component as it may reduce relative injury risk for professional soccer players in the subsequent week.
- Moderate-low and high ACWR should be considered an injury risk flagging factor for the subsequent week. Programme periodization should avoid these workload index's.

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Chapter Four

Article Two: Quantifying the injury risk associated with mechanical workload among professional soccer players utilising the acute:chronic workload ratio.

This article will be submitted for publication in the *British Journal of Sports Medicine*. The article is herewith included according to the guidelines for authors of this esteemed journal. However, to provide a neat and well-rounded final product for this thesis, the article has been edited to represent a published article as it would appear in this particular journal. This does not imply that the article has been accepted or will be accepted for publication. Subsequently, the referencing style, font, figures and tables used in this chapter may differ from that used in the rest of the chapters of this thesis.

Quantifying the injury likelihood associated with mechanical workload among professional soccer players utilising the acute:chronic workload ratio

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ABSTRACT

Aim The aim of this study was to investigate the association between GPS and accelerometer-derived mechanical load indicators and non-contact injury likelihood, utilising the acute:chronic workload ratio (ACWR) among professional soccer players.

Methods The workload data and injury incidence of 37 players were monitored over 1.5 seasons. Generalised estimation equations (GEE) were used to model the relationship between the ACWR and injured vs. non-injured players for specific GPS and accelerometer derived variables: total distance (TD), high intensity speed (HIS), high intensity accelerations (HIA) and high intensity decelerations (HID). Odds ratios (OR) and 95% confidence intervals (CI) were calculated to determine which load indicators increased or decreased the likelihood of injury. Magnitude based inferences (MBI) were used to interpret the real-world relevance of the results.

Results In total, 61 non-contact injuries were recorded. A sigmoidal workload-injury relationship was observed for TD, HIS and HID, while a quadratic relationship was observed for HIA. Likely harmful effects were found for high (TD: ≥ 1.30 ; HIS: ≥ 1.41 ; HIA: ≥ 1.37), moderate-high (HID: 1.18-1.37) and low (HIA: < 0.77) ACWR.

Conclusions Acute de-load and spikes in workload were associated with increased non-contact injury likelihood in the subsequent week. A moderate ACWR of between ~ 0.91 and ~ 1.20 , represents the most practical and realistic training load index to maintain or improve fitness and preparedness, while limiting injury likelihood compared to high and low ACWR.

INTRODUCTION

The intermittent, high metabolic, and mechanical demands of soccer training and match play place considerable physiological and biomechanical stress on the body.^{1,2} Soccer is continuously evolving, becoming faster, more intense and ultimately more taxing for professional players.³ Coaches are under increasing pressure to achieve success, and thus, continually test the limits of

what their players are capable of and what their bodies can withstand.⁴

According to Banister *et al.*,⁵ the performance of an athlete can be predicted by the difference between a negative function (i.e. ‘fatigue’) and a positive function (i.e. ‘fitness’). Morton⁶ expanded on this principle by suggesting that a training stimulus should not be so high as to induce excessive fatigue, (i.e. limiting performance and increasing injury risk), nor too low so as to prevent improvements in fitness (i.e. limiting adaptation).⁶ Hence, the ideal training stimulus is one that maximises performance potential by striking an appropriate balance between training, competition and recovery (i.e. limiting negative consequences such as injury, illness and overtraining).⁶

Bowen *et al.*,⁷ noted that this balance is not always achieved which may lead to high injury rates in professional soccer. On average, a professional player may sustain two injuries per season, resulting in injury absence of 37 days in a 300-day season.⁸ This injury induced absence may be detrimental to a team’s success and have financial ramifications for professional soccer clubs.⁹ Recently, it was proposed that non-contact injury should be considered as a consequence of overloading or under-loading, and given that training load is modifiable and controllable, the ensuing injury can be considered the result of a ‘training load error’ (i.e. inappropriate training load prescription).¹⁰ Therefore, preventing these ‘training load errors’ by monitoring workloads is vital to achieve an ideal training stimulus, which ultimately may ensure positive training adaptation and reduce the risk of injury for professional soccer players.^{4,10}

One popular workload monitoring method, which objectively quantifies mechanical load by using electronic tracking systems, entails the use of global positioning systems (GPS).¹¹ The use of

GPS and accelerometer-derived workload measures, allowed researchers to identify high injury risk conditions which were caused by rapid increases in absolute acute load,^{4 12 13} high accumulated loads^{13 14} and low accumulated loads.¹⁵ These absolute and accumulated loads provide evidence that the workload-injury relationship is non-linear and studies both in rugby union¹⁶ and cricket¹⁷ have reported a u-shaped relationship. This suggests that an optimal load range may exist which offers the exposed athletes the lowest relative likelihood of injury, compared to higher and lower workload ranges. However, categorising injury likelihood by absolute workloads may not completely explain injury for all players due to the manner in which individuals respond physiologically to the mechanical demands of soccer.¹⁸ Therefore, a training load index is required which considers acute absolute workloads as well as chronic accumulated workloads. One such index is the acute:chronic workload ratio (ACWR).¹⁷

The ACWR compares the absolute workload performed in 1-week (i.e. acute load) relative to the 4-week chronic workload (i.e. 4-week average acute workload).¹⁷ The acute workload is indicative of the fatigue an athlete is currently experiencing, while the chronic workload is indicative of an athlete's fitness. Therefore, the comparison of fitness to fatigue provides a dynamic representation of an athlete's preparedness and ultimately considers the training load performed relative to the training load the athlete has adapted to.^{19 20} The use of this model Gaelic football showed that athletes experienced an increased risk of injury when the acute workload was double that of the chronic workload.²¹ Similarly in cricket, fast bowlers were three times more likely to sustain an injury when their acute workload was double that of their chronic workload.¹⁷ Interestingly, while high acute workloads increased the risk of injury in Gaelic football and cricket, research conducted in Australian football found that low ACWR also predisposed athletes to significant injury risk.¹⁵ These asymmetrical injury risk findings with regards to high and low workload suggest that the workload-injury relationship is possibly u-shaped, with high injury risk observed at both low and high ACWR, while a moderate ratio may offer protective effects.

Despite these findings, there is limited research exploring the contribution of GPS and

accelerometer-derived mechanical load indicators and injury likelihood in professional soccer. Furthermore, few studies have examined and reported the nature or shape of the workload-injury relationship with regards to the ACWR. Therefore, this study aimed to examine the nature and association between mechanically-derived ACWR and injury likelihood in the subsequent week among professional soccer players.

METHODS

Participants

Data was collected from elite senior soccer players (n=37) from one South African Premier Soccer League (PSL) club (mean age: 24.5±3.6 years; stature: 176.3±6.6 cm; body mass: 74.4±7.9 kg). The players trained on a full-time basis and played competitive league and cup fixtures in the PSL during the full 2016-2017 and half of the 2017-2018 season. Ten (27%) participants competed in both seasons and twenty-seven (73%) competed in one season, resulting in 47 complete data sets over the 1.5 seasons of data collection. As proposed by similar investigation goalkeepers were excluded due to the different nature of their physical activities.⁷ Ethical approval was obtained from the university Research Ethics Committee (SPORT-2017-0162-121).

Definition of injury

Injury information was classified by the PSL clubs' doctor and senior physiotherapist, collated, then added and updated to the clubs' database. A recordable injury was defined as one that caused any absence from any training or match play (time-loss).²¹ Injuries were categorised by injury type (description) and body site (injury location). The mechanism of injury was further classified as either contact or non-contact in nature. Only time-loss, soft-tissue non-contact injuries were included in this study.

Quantifying workload

Workload was quantified using GPS (VX Systems™, New Zealand) and data was collected from all on-pitch training sessions and matches. The GPS units were placed between the scapulae of the players in bespoke vests. These units sampled at 10Hz and the internal accelerometers at 100Hz. Upon completion of training sessions and/or matches, the data was downloaded using specialized software (provided by the GPS company).

For sessions when the GPS data was unavailable for a participant (n=420 of 4 776; 8.8%) because; he was not wearing a unit, could not complete a full session, or units were not available, the data was estimated as follows: Training session data was estimated by calculating the squad average, and match data was estimated using position-specific season game averages,

while considering individual match time. These methods are in accordance with previously conducted workload studies in professional soccer.^{7 13} The variables defined in Table 1 were selected for use in this study due to their relevance to the mechanical demands of soccer actions and potential non-contact soft-tissue injury.^{7 22}

Variable	Definition
TD	Sum of the total distance covered (m) - this includes walking, jogging, fast running and sprinting.
HIS	Sum of the total distance covered (m) above 15 km/h.
HIA	The frequency (i.e., count) of changes in GPS speed data with an acceleration at or above 3.0 m/s/s.
HID	The frequency (i.e., count) of changes in GPS speed data with a deceleration at or above 3.0 m/s/s.

GPS, global positioning system; TD, total distance; HIS, high intensity speed; HIA, high intensity acceleration; HID, high intensity deceleration.

Data analyses

Data was categorised in weekly blocks from Monday to Sunday. The acute workload was calculated as the sum of all work for 1-week, and chronic workload as the 4-week rolling average of the workload sum total for each of the preceding 4 weeks. The ACWR was calculated by dividing the acute workload by the chronic workload.¹⁷ A value of > 1.00 represents an acute workload greater than the chronic workload and a value of < 1.00 represents an acute workload less than the chronic workload.⁷ Workload data were divided into quintiles so that injury likelihood could be assessed in each workload category, these categories were labeled low, moderate-low, moderate, moderate-high and high, so as to aid interpretation of the results. The moderate category was utilised as the reference group to compare injury likelihood with lower and higher categories.

Statistical analyses

The analysis was performed in a manner similar to the work of Jaspers *et al*¹³ and McCall *et al*.²³ Injury incidence was determined by dividing total number of injuries by the 'on-legs' exposure time and reported as rates per 1000 hours.²¹ In order to examine the nature of the workload-injury relationship, the relative injury likelihood was calculated as the number of injuries sustained in relation to the number of exposures to each workload category, and expressed as a percentage (%).²⁴ To assess the workload-injury association in the subsequent week a generalized estimating equation (GEE) analysis was utilised due to its ability to account for the correlated nature of repeated measures data, making it superior to

previously utilised logistic regression methods.²⁵ The model was set for a binary distribution (1 for injured and 0 for non-injured) and all workload variables were modelled independently as predictor variables. For comparisons between the risk of non-contact injury in different workload categories, odd ratios (OR) and 95% confidence intervals (95% CI) were calculated.

Results of clinical and practical significance are often overlooked due to non-significant ($p > 0.05$) null-hypothesis tests, which may fail to account for the real-world importance of an effect.^{26 27} As such, magnitude-based inferences (MBI) were used to interpret the p-value and the value of the OR between categories, allowing for the calculation of the probability that the true effect was harmful, trivial and/or beneficial.^{28 29} The smallest beneficial and harmful effect for an OR was considered as <0.90 and >1.11, respectively.^{23 29} If the effect was considered clear, thresholds for assigning qualitative terms of beneficial, trivial, harmful were as follows: <0.5%, most likely; >0.5%-2.5%, very unlikely; >2.5%-25%, unlikely; >25%-75%, possible; >75%-95%, likely; >95%-99.5% very likely; >99.5% most likely. Practical significance was reached when the probability that the true effect was either harmful or beneficial was $\geq 75\%$ likely.²⁹

RESULTS

Injury incidence

A total of 61 non-contact injuries (6.8/1000 hours 'on-legs' exposure time) were recorded during the study (2016-2017, 6.7/1000 hours; 2017-2018, 7.0/1000 hours) (see Table 2). The hip/groin was

the most common site of non-contact injury (2.6/1000 hours) with hamstring injuries close behind (2.4/1000 hours). Muscular strains/tears were the most common injury type (5.6/1000

hours). Overall, injuries sustained in competition were more common (7.3/1000 hours) compared to injuries sustained during training (6.3/1000 hours).

Table 2 Classification of non-contact injuries per 1000 hours

	2016-2017	2017-2018	Total
(Per 1000 hours)	Non-Contact (6.7)	Non-Contact (7.0)	Non-Contact (6.8)
Site			
Ankle/foot	0.1	0.7	0.4
Knee	0.5	0.3	0.4
Hip/groin	1.8	3.3	2.6
Quadriceps	1.0	0.3	0.6
Hamstring	2.8	2.0	2.4
Forearm/wrist/hand	0.0	0.0	0.0
Head/neck	0.0	0.0	0.0
Abdomen/lower back	0.2	0.1	0.1
Lower Leg	0.3	0.3	0.3
Shoulder/arm/elbow	0.0	0.0	0.0
Sternum/ribs/upperback	0.0	0.0	0.0
Injury type			
Ligament sprain/tear	0.4	0.3	0.3
Muscle strain/tear	5.8	5.3	5.6
Tendinosis	0.3	1.0	0.6
Other	0.2	0.4	0.3
Activity performed			
Match	7.1	6.3	6.7
Training	6.3	7.8	7.0

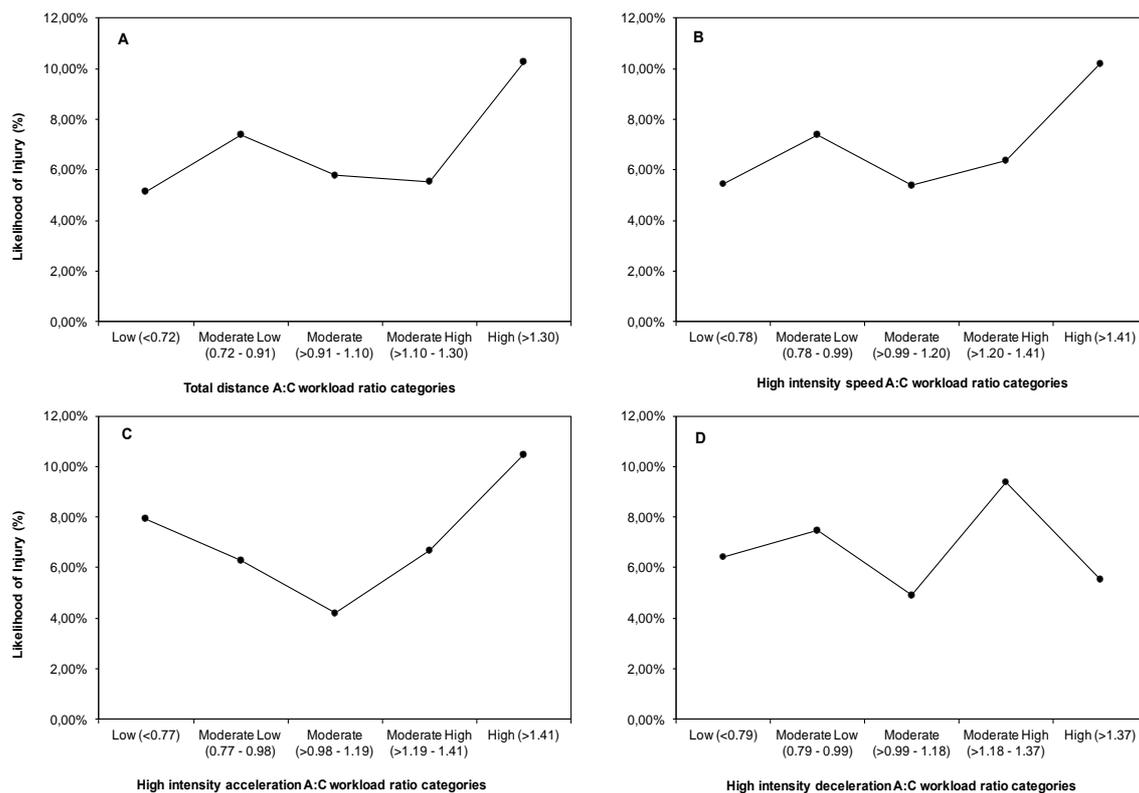


Figure 1 A:C workload ratio vs likelihood of injury: TD (A), HIS (B), HIA (C) and HID (D) in the subsequent week.

A:C workload ratios and injury likelihood

Total distance (TD)

A sigmoidal (s-shaped) curve was observed between TD ACWR and non-contact injury in the subsequent week (Figure 1A). The lowest injury likelihood was observed at a low ACWR (TD: <0.72, 5.13%) and the highest injury likelihood was detected at a high ACWR (TD: >1.30, 10.24%). A likely harmful effect was found at a high ACWR (TD: >1.30, OR=1.78, 95% CI 0.72-4.38) (Figure 2A).

High intensity speed (HIS)

A sigmoidal (s-shaped) curve was observed between HIS ACWR and non-contact injury in the subsequent week (Figure 1B). The lowest injury likelihood was noted at a moderate ACWR (HIS: 0.99-1.20, 5.39%) and the highest injury likelihood was detected at a high ACWR (HIS: >1.41, 10.19%). A likely harmful effect was found at a high ACWR (HIS: >1.41, OR=1.74, 95% CI 0.80-3.77) (Figure 2B).

High intensity accelerations (HIA)

A quadratic (u-shaped) curve was observed between HIA ACWR and non-contact injury in the subsequent week (Figure 1C). The lowest

injury likelihood was detected at a moderate ACWR (HIA: 0.98-1.19, 4.23%) and the highest injury likelihood was detected at a high ACWR (HIA: >1.41, 10.48%). Due to the quadratic relationship between HIA ACWR and non-contact injury likelihood, a high injury likelihood was also observed at a low ACWR (HIA: <0.77, 7.94%). A likely harmful effect was found at a low ACWR (HIA: <0.77, OR=1.29, 95% CI 1.00-1.66) and at a high ACWR (HIA: >1.41, OR=1.80, 95% CI 1.00-3.24) (Figure 2C).

High intensity decelerations (HID)

A sigmoidal (s-shaped) curve was observed between HID ACWR and non-contact injury in the subsequent week (Figure 1D). The lowest injury likelihood was found at a moderate ACWR (HID: 0.99-1.18, 4.92%) and the highest injury likelihood was detected at a moderate-high ACWR (HID: 1.18-1.37, 9.40%). A likely harmful effect was found at a moderate-high ACWR (HID: 1.18-1.37, OR=1.61, 95% CI 0.86-3.03) (Figure 2D). Interestingly, a high ACWR was not associated with a high injury likelihood (HID: >1.37, 5.52%) or a likely (or >) harmful effect (HID: >1.37, OR=0.80, 95% CI 0.39-2.76) (Figure 2D).

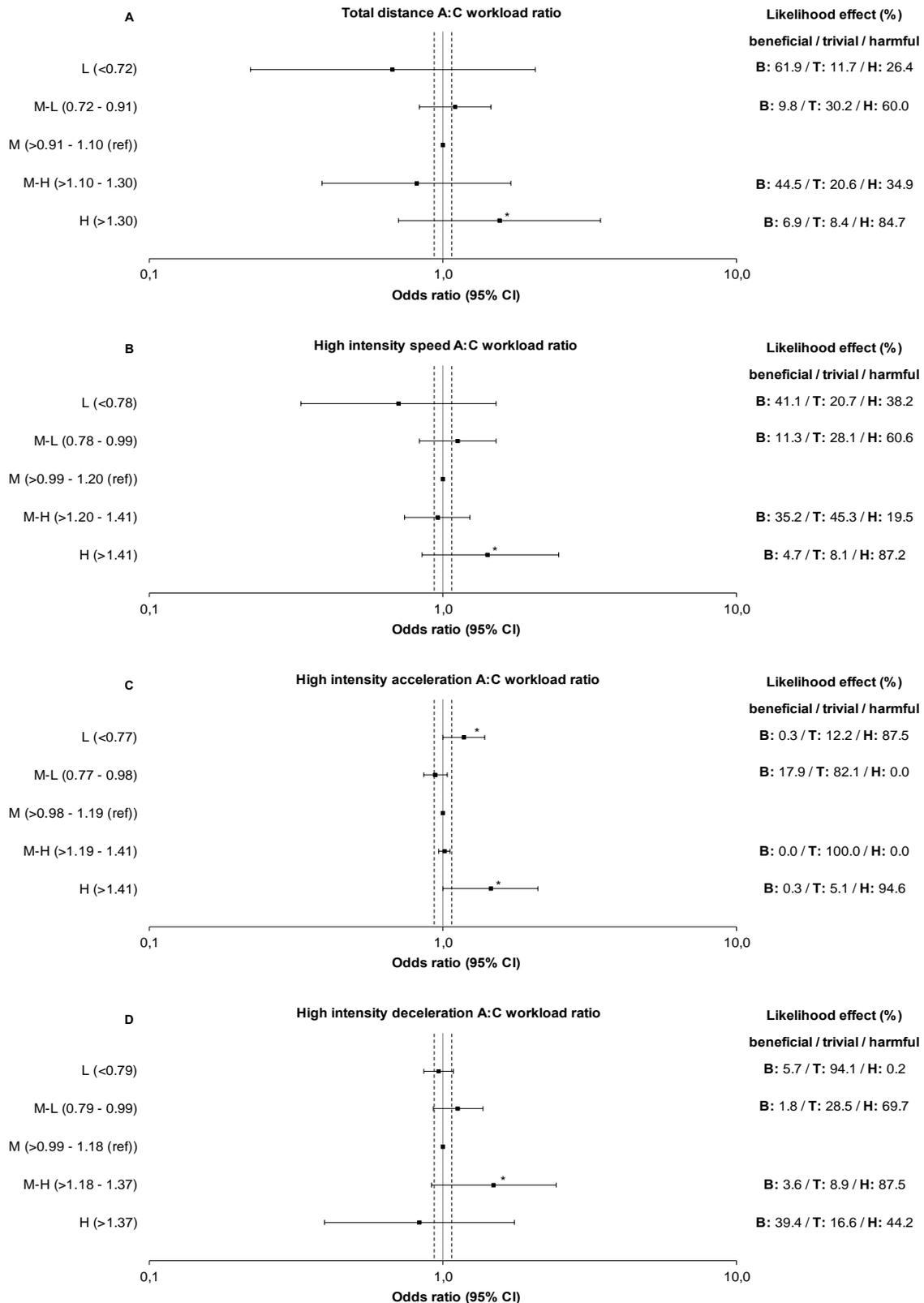


Figure 2 Injury likelihood for TD (A), HIS (B), HIA (C) and HID (D) ACWR at low, moderate-low, moderate-high and high loads compared to the moderate ACWR category (i.e. the reference category). Smallest worthwhile changes in injury likelihood are displayed as dotted lines. Likelihood effects are shown in percentages. † = Likely beneficial, †† = very likely beneficial, ††† = most likely beneficial, * = likely harmful, ** = very likely harmful, *** = most likely harmful.

DISCUSSION

This study provides additional evidence for the use of the A:C workload ratio by using GPS/accelerometer-derived workload indicators to evaluate injury likelihood in the subsequent week for professional soccer players. Harmful effects were found for players exposed to high TD, HIS, HIA, moderate-high HID and low HIA A:C workload ratio. Additionally, the workload-injury relationship was sigmoidal (s-shaped) for TD, HIS and HID, and quadratic (u-shaped) for HIA. These findings demonstrate that large acute fluctuations in mechanical load increase the likelihood of injury in the subsequent week, and that the workload-injury relationship is non-linear in nature.

Previous studies have reported associations between high A:C workload ratio and all forms of injury.^{7 13 15 17} Results from this study add to the existing literature by reaffirming that increased injury likelihood is associated with high A:C workload ratio. The original A:C workload ratio model was based on performance³⁰ and this was subsequently related to injury risk.¹⁷ Banister *et al*⁵ suggested that acute workload could be viewed as an estimate of an athlete's fatigue, while the chronic workload could be viewed as an estimate of an athlete's fitness. In the context of this study, a large discrepancy between an athletes' fatigue and fitness resulted in a greater injury likelihood than when the ratio was moderate or low. This suggests that a higher level of fatigue (acute workload) relative to an athlete's fitness (chronic load foundation) is related to increased injury likelihood in the subsequent week. These findings are similar to studies conducted in cricket¹⁷ and Australian football,¹⁵ in which an acute spike in mechanical workload relative to an athlete's chronic load foundation significantly increased the likelihood of injury.

Interestingly, while high A:C workload ratio demonstrated likely harmful effects compared to moderate ratios, the nature of the workload-injury relationship (Figure 1) suggested that a moderate-low ratio also increased injury likelihood (TD: 7.4%, HIS: 7.4% and HID: 7.5%) compared to a moderate ratio (TD: 5.8%, HIS: 5.4% and HID: 4.9%). However, the magnitude of this effect was deemed 'unclear' as it lacked practical significance.²⁶ The only exception to this trend was observed for HIA in which a low ratio displayed a likely harmful effect and the workload-injury relationship was quadratic rather

than sigmoidal in nature. The increased injury likelihood observed with low and moderate-low A:C workload ratio may be indicative of the lowering of an athletes' chronic load foundation.¹⁵ This lowering of the chronic load foundation may result in a state of under-preparedness for the mechanical demands of soccer that follow and subsequently increases the likelihood of injury.⁷

Collectively, these findings suggest that increased injury likelihood is associated with acute de-load and spikes in mechanical load and that a moderate A:C workload ratio offers the lowest relative injury likelihood or a 'protective effect' in comparison. This is reminiscent of Gabbetts³¹ injury prevention paradox, in which inappropriately prescribed training load either overloaded or underprepared an athlete for the competitive demands of the sport and subsequently increased the likelihood of injury. Ultimately, a specific level of training is required to develop the physical capacities needed to withstand the physical demands of the sport.³¹ Players who train consistently may therefore develop a greater resilience and tolerance for the mechanical requirements of professional soccer, resulting in a level of protection from injury.^{3 32} This may explain why moderate A:C workload ratio demonstrated the lowest injury likelihood; players trained enough to maintain and safely progress their chronic load foundation, while limiting the negative consequences of overtraining and fatigue.³² This 'protective' workload category is described as the training 'sweet spot'.³³

Previous research indicated a sweet spot for the A:C workload ratio between 0.80 and 1.30 however, these values were derived from an amalgamation of cricket, rugby league and Australian football data.³³ Research in professional soccer has reported a comparable 'sweet spot' relationship for an A:C workload ratio between 0.87 to 1.12 using mechanical load indicators.¹³ Our data seems to suggest a similar relationship, in that the lowest injury likelihood was observed within similar A:C workload ratio for all variables (Figure 1 and 2) and likely harmful effects were found at high TD, HIS and HIA, moderate-high HID and low HIA categories when compared to a moderate A:C workload ratio. These findings demonstrate the multifactorial, non-linear nature of injury in professional soccer.

In summary, to reduce the injury likelihood for professional soccer players, practitioners should ideally prescribe a training load that is both high

enough to adequately prepare players for the mechanical demands of the sport (i.e. induce adaptation and improve performance), while preventing underloading and overtraining. Our findings suggest that a moderate A:C workload ratio of between ~0.91 to ~1.20 (Figure 2), represents the most realistic and optimal training load index which may maintain or improve fitness and preparedness, while limiting injury likelihood compared to high and low A:C workload ratio. This training load index represents an acute workload (i.e. fatigue level) roughly ~9% less and up to ~20% above the chronic load foundation (i.e. fitness). To put it simply, exposing players at and slightly above the mechanical demands of what they are prepared for, while limiting an acute de-load or spike may reduce injury likelihood in the subsequent week for professional soccer players.

LIMITATIONS

Several limitations should be acknowledged in this study. Despite the quantification of mechanical workload using GPS and accelerometers, the players participated in other conditioning sessions (e.g. gym) as well as the on-field sessions that could not be quantified by GPS and these workloads were not considered in the study. Additionally, while players were away on national duty and/or holiday, no workload data was collected or was not filtered back to the club and could not be considered in this study. The GPS system that was used had a sampling frequency of 10Hz which allowed for valid and reliable quantification of the mechanical load.³⁴ However, a measurement error has been reported to occur with increase in speed which needs to be taken into account when interpreting the data.³⁵ Furthermore, while modifiable injury factors were accounted for (i.e. mechanical load: TD, HIS, HIA and HID), non-modifiable factors like age and injury history were not.³⁶

CONCLUSION

This study highlights the effect of inappropriate mechanical load prescription on injury likelihood in the subsequent week for professional soccer players. Furthermore, the results demonstrate a quadratic and sigmoidal workload-injury relationship. In order to reduce injury likelihood, practitioners should avoid the harmful effects of high TD, HIS and HIA, moderate-high HID and low HIA A:C workload ratio categories.

PRACTICAL IMPLICATIONS

- Findings of this study provide further evidence for the use and implementation of the ACWR in professional soccer to reduce the injury likelihood associated with inappropriate mechanical load prescription.
- Spikes in acute workload are associated with increased non-contact injury likelihood in the subsequent week.
- Low HIA A:C workload ratio should be considered an additional injury factor which may increase the likelihood of injury in the subsequent week.
- Maintaining an A:C workload ratio slightly below and above an athletes' chronic load foundation (~0.91 to ~1.20 in this study) may lower the likelihood of injury in the subsequent week for professional soccer players.

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Chapter Five

CONCLUSION AND RECOMMENDATIONS

5.1 LITERATURE OVERVIEW

The reviewed literature highlighted that professional soccer players are subjected to long competition calendars, and high TLs without adequate rest in an attempt by their coaches to improve performance. These demands, coupled with the inherent physiological, metabolic, and mechanical requirements of professional soccer, result in high injury rates among professional players. Emphasis has been placed on the development and improvement of TL monitoring protocols owing to the impaired financial and performance ramifications stemming from these high injury rates. The literature addressed the current state and practice of TL monitoring and emphasised the need to monitor both internal and external TL metrics. Additionally, the review allowed for the identification of methods which accurately quantified and described the training process among professional soccer players. Specifically, sRPE and GPS and accelerometer-derived workload variables were found to be reliable and valid measures to quantify the training process. The ACWR was highlighted as a method which addresses the pitfalls of other TL monitoring methods which don't account for both the acute fatigue and chronic fitness of a player. As such, the ACWR provides a dynamic representation of preparedness and ultimately considers the TL a player experiences, relative to the TL that they are accustomed to.

The reviewed literature further showed that by making use of the ACWR method, high and low injury risk conditions could be identified in a variety of team sports. Two possible models for quantifying the ACWR were identified namely, the EWMA model and the RA model. The RA model was selected for use in this study because the literature indicated that while the EWMA model showed promise, a lack of previous validation existed. The RA model was evidence-based and considered standard practice for current TL monitoring research in team sports. Therefore, the current study aimed to explore and analyse the relationship between both internally and externally-derived ACWR and injury risk or injury likelihood in the subsequent week among professional soccer players.

5.2 CONCLUSION

The study aimed to meet three objectives for both internally and externally-derived ACWR. Conclusions are made against each of these objectives.

5.2.1 Objective one: To determine the association between the ACWR and injury risk or injury likelihood in the subsequent week.

- Internally-derived acute chronic workload ratio (ACWR)

The analysis revealed that internally-derived (sRPE) ACWR was significantly associated ($p < 0.05$) with non-contact injury occurrence in the subsequent week when modeled univariately with cumulative workloads. The various cumulative workloads showed no significant associations with injury occurrence in the subsequent week. Further analysis indicated that different sRPE ACWR zones demonstrated varying magnitudes of injury risk, some increasing injury risk while others displayed reductions in risk for the subsequent week.

- Externally-derived acute chronic workload ratio (ACWR)

A similar analysis was performed using the externally-derived (GPS and accelerometer) ACWRs to assess injury likelihood in the subsequent week. This analysis identified that all of the selected external workload variables (total distance, high intensity speed, high intensity acceleration and high intensity deceleration) were significantly associated (i.e., the probability of the true effect was $\geq 75\%$ likely) at specific ACWR zones with varying degrees of injury likelihood in the subsequent week.

Together these findings provide further evidence that the ACWR, regardless of the TL metric utilised in its calculation (i.e., internal: sRPE and/or external: TD, HIS, HIA and HID GPS) is significantly associated with injury occurrence and injury risk or likelihood in the subsequent week.

5.2.2 Objective two: To analyse and describe the shape of the workload-injury relationship with regards to the ACWR.

- Internally-derived acute chronic workload ratio (ACWR)

The internally-derived workload-injury relationship was non-linear in nature (i.e., increasing workload in terms of the ACWR did not necessarily result in higher

injury likelihood in the subsequent week). These asymmetrical findings were sigmoidal (s-shaped) in nature and indicate that players exposed to different workload zones (in terms of the ACWR), experienced varying degrees of injury likelihood in the subsequent week.

- Externally-derived acute chronic workload ratio (ACWR)

The externally-derived workload-injury relationship was non-linear in nature for all GPS and accelerometer TL metrics, and increasing workload in terms of the ACWR did not necessarily result in higher injury likelihood in the subsequent week. These asymmetrical findings were sigmoidal (s-shaped) or quadratic (u-shaped) in nature and indicate that players exposed to different workload zones (in terms of the ACWR) experienced varying degrees of injury likelihood in the subsequent week.

Together these findings provide further evidence that the workload-injury relationship is multifactorial and that specific workload conditions can predispose a player to increased or decreased injury risk in the subsequent week.

5.2.3 Objective three: To identify and assess which ACWR conditions either increase or decrease injury risk/injury likelihood in the subsequent week.

- Internally-derived acute chronic workload ratio (ACWR)

Different sRPE ACWR zones were associated with varying levels of injury risk in the subsequent week. Beneficial effects were observed for players exposed to low ACWR (< 0.72), while a high ACWR (> 1.14) was likely harmful to exposed players in the subsequent week. Notably, a moderate-low ACWR displayed most likely harmful effects to exposed players in the subsequent week when compared to a moderate-high ACWR of between 1.04 to 1.14.

- Externally-derived acute chronic workload ratio (ACWR)

With regards to the externally-derived (GPS and accelerometer) ACWR variables (total distance, high intensity speed, high intensity acceleration and high intensity deceleration), specific ACWR zones were found to increase the likelihood of injury in the subsequent week for exposed players when compared to a moderate ACWR zone. Likely harmful effects were found for high total distance (> 1.30), high, high-intensity speed (> 1.41), high, high-intensity acceleration (> 1.41) and

moderate-high, high intensity deceleration ($> 1.18-1.37$) ACWRs. Interestingly, while high and moderate-high ACWR were generally associated with an increased injury likelihood, a low high intensity acceleration (< 0.77) ACWR demonstrated a likely harmful effect.

Together these findings suggest that players who were exposed to large acute TL fluctuations greater than their individual chronic load foundation experienced a higher likelihood of injury in the subsequent week. Interestingly, while acute TL spikes increased the likelihood of injury, acute de-loads in TL relative to a player's chronic load foundation was also associated with an increased likelihood of injury in the subsequent week. These findings are mirrored in the reported workload-injury relationship which was found to be non-linear and sigmoidal (s-shaped) in nature.

5.3 IMPLICATIONS FOR PRACTITIONERS

The results of the study revealed that both internally-derived (sRPE) and externally-derived (GPS and accelerometer) ACWR are associated with non-contact injury likelihood in the subsequent week among professional soccer players. These findings highlight the similarities between internally-derived (sRPE) and externally-derived (GPS and accelerometer) ACWR, in that high and low ACWR increased the likelihood of subsequent injury when compared to a moderate ACWR. These similarities are further strengthened by the nature of the workload-injury relationship, which was non-linear and sigmoidal. There are three main implications for practitioners to consider regarding these findings.

5.3.1 Session rating of perceived exertion (sRPE) as a useful alternative

Quantifying what a player has done, relative to what they are prepared for, in the form of the ACWR, allows for the identification of potential injury risk conditions. The findings of this study suggest that this relationship holds true regardless of the TL metric utilised (i.e., internal: sRPE or external: GPS and accelerometer). This implies that sRPE may be a useful alternative to costly GPS systems, more so in low-resourced environments, which is an important implication for the South African context.

5.3.2 The sigmoidal workload-injury relationship

The results revealed that high and low ACWR increased the likelihood of subsequent injury when compared to a moderate ACWR. The implication of these findings is noteworthy, in that a moderate ACWR zone of approximately ~ 0.91 to ~ 1.20 (for all the analysed TL metrics) seems to offer the lowest likelihood of subsequent injury compared to higher and lower ACWR zones. This sigmoidal relationship can be seen below in Figure 5.1.

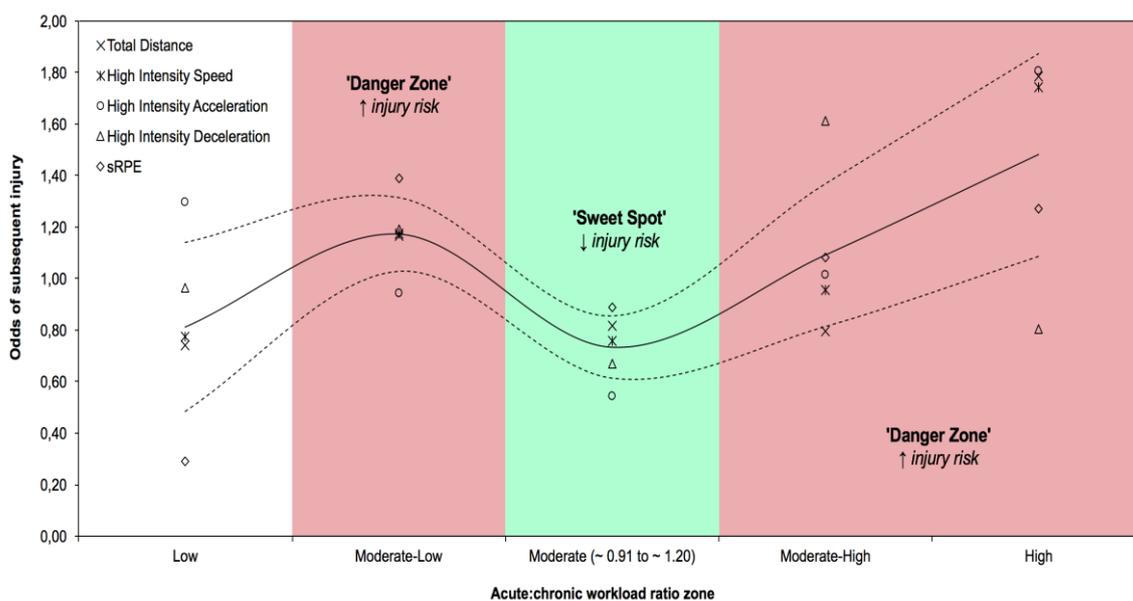


Figure 5.1 The sigmoidal workload-injury relationship. An amalgamation of all the analysed TL metrics, grouped according to the ACWR zone and the associated OR. The solid black line represents the mean OR for each ACWR zone, while the dotted lines represent one standard deviation above and below the mean.

The sigmoidal workload-injury relationship observed above significantly differs from other previously reported workload-injury relationships, namely Gabbetts' u-shaped curve discussed in chapter two of this thesis. The authors believe that there are three possible explanations for the observed differences between the workload-injury relationships (i.e., u-shaped vs s-shaped), namely:

- The methodological differences - Earlier research utilised statistical analysis methods which did not accurately account for the longitudinal, non-linear and inter-correlated nature of training load data (i.e., logistic regression vs

generalised estimation equations) (Carey *et al.*, 2018). Additionally, the earlier literature lacked consistency and was unclear regarding the reference group utilised for the analysis, which may have introduced bias into the described workload-injury relationship upon the conclusion of said earlier studies.

- The type of sport - The earlier reported u-shaped workload-injury relationship was an amalgamation of rugby, Australian football and cricket data (Gabbett, 2016a). The current study focused on only soccer data and the authors believe that the physiological, psychological, technical and professional differences or demands may explain the differences observed between the curves.
- The research cohort utilised - The authors also believe that the workload-injury relationship identified is best suited to the cohort or population from which it was derived. Thus, different cohorts may exhibit different workload-injury relationships.

5.3.3 Optimal workload range

The implication of the above finding is that a moderate ACWR zone represents a TL index that is high enough to adequately prepare players for the demands of the sport (i.e., induce fatigue and subsequent adaptation to maintain physical condition), while preventing underloading and overtraining. Practitioners should utilise this TL index otherwise known as the 'sweet spot', because it represents the most realistic and optimal TL index to maintain or improve fitness and/or preparedness, while limiting injury likelihood compared to high and low ACWR.

5.3.4 Summary

In summary, by quantifying the magnitude of the fitness-fatigue relationship (ACWR) and exposing players at and slightly above the demands of what they are prepared for, while limiting an acute de-load or spike in TL, may result in reduced injury likelihood in the subsequent week among professional soccer players.

5.4 IMPLICATIONS FOR FUTURE RESEARCH

If the current study was to be continued and/or replicated, the following

implications should be considered. The authors took into account the revised literature and the results of the study in order to identify key areas for future exploration.

5.4.1 The acute chronic workload ratio (ACWR) model

The current study utilised the RA model to calculate the ACWR. However, future research should investigate the EWMA ACWR model in conjunction with the RA ACWR model. This investigation may provide information detailing which model exhibits a stronger association or sensitivity with injury likelihood, thereby improving the efficiency and accuracy of TL monitoring protocols (with regards to injury prevention) in professional sports.

5.4.2 Daily vs. weekly acute chronic workload ratio (ACWR)

The current study utilised weekly ACWR values to assess injury risk in the subsequent week. Future research should consider calculating daily ACWR to assess the injury risk over shorter lag periods of days, rather than a week. Potential information gleaned from research such as this may assist sport science practitioners in developing a deeper understanding of the workload-injury relationship, and how subsequent injury risk is affected by daily variation in TL rather than weekly variation.

5.4.3 Multivariate vs. univariate analysis

The current study identified injury risk in the subsequent week that was associated with specific TL metrics (relative to a certain ACWR zone) in isolation (i.e., univariately). However, the workload-injury relationship is multidimensional in nature (i.e., many factors affect an athlete's risk of injury) therefore, to account for the multifactorial nature of injury, future research should attempt to incorporate TL, lifestyle factors and/or wellness variables into a multivariate analysis. A multivariate analysis may provide deeper insight into injury occurrence and assist sport science practitioners by highlighting which metrics are important to collect, monitor and analyse so as to reduce an athlete's risk of subsequent injury.

5.4.4 Individual vs. team analysis

The researchers suggest that future study should consider identifying whether

individual athletes exhibit the same workload-injury relationship as identified within group analysis. It stands to reason that if individual athletes responded to TL differently, are of different ages, and have different injury histories, that an in-depth analysis may yield more specific individualised workload-injury relationships. Individually identified responses to TL and workload-injury relationships may assist sport science practitioners in developing more efficient and effective TL monitoring systems.

5.5 STUDY LIMITATIONS

Several limitations should be acknowledged in this study. During international breaks and off-season periods, workload data was; a) not collected, b) was collected, but not available and/or c) was collected but not available due to different collection methods or systems. Therefore, this data was not analysed as part of the study. Additionally, some field training sessions could not be quantified by GPS and this workload data was not considered for the purpose of this study. There are many factors which impact on injury likelihood (e.g., previous injury, fatigue and age, etc.), however, only components of internal (sRPE) and external (GPS and accelerometer) workload data were accounted for in the current analysis. The GPS system that was used had a sampling frequency of 10 Hz which allowed for valid and reliable quantification of the external workload. However, a measurement error has been reported to occur with increase in speed which needs to be taken into account when interpreting the data. Additionally, a lack of validation exists for GPS integrated accelerometers and this too needs to be taken into account when interpreting the current findings.

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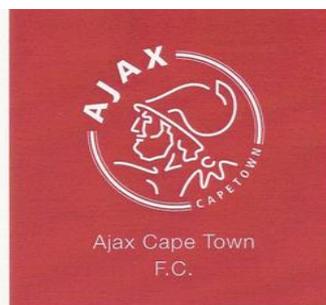
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APPENDICIES

Appendix A - letter of permission



To whom it may concern,

Hereby I confirm, in my capacity as the head of medical and performance of Ajax Cape Town Football club, that we are fully supportive of the masters degree research study of mr. Ryan White, entitled "The Acute: Chronic Workload Ratio and Injury Occurrence Among Elite South African Male Soccer Players".

We would like to grant permission for the collection of the injury data of the Ajax Cape Town PSL squad as well as their training and match load data, namely the sRPE and corresponding GPS data. This study will contribute directly towards better management of our players and improving their health, fitness and performance. Mr. White assists us with the gathering of this information and has done so, since being appointed the fitness intern in October of 2016, during the 2016/2017 season. To have him analyse this information systematically as part of a thesis would be beneficial to the club and help us to strategise in the future.

Mr White explained to me that there may be a problem with obtaining ethical clearance for the information collected for the start of the 2016/2017 season – in the same time period in which he wants to collect data at the start of the new season (2017/2018). As the analysis of this data will add greater value and is very important to the development of the team, I would like to request that permission also be given for the data collected for the season which is presently underway.

I am happy with this arrangement as I understand that the data will be reported and analysed in an anonymous way and the data is already collected as part of the standard operating procedure of Ajax Cape Town. Furthermore, I understand that the identity of the club will be not be advertised, but I accept that based on the analysis it may be possible to identify which team the data applies to. I would like to state that I do not see this as a concern.

Yours sincerely,

JANTHO GREYLING

HEAD OF MEDICAL AND PERFORMANCE

AJAX CAPE TOWN FOOTBALL CLUB (PTY) LTD

Directors: A Efstathiou, C Efstathiou, N Efstathiou, J Slop*, M Overmars*, C Groenendijk* (*Dutch)

onr Frans Conradie Drive & Bertie Genade Street, Parow 7500, P.O.Box 926, Parow 7499, South Africa

Tel.: +27 21 930 6001 - Fax: +27 21 939 6403 - E-mail: info@ajaxct.co.za - www.ajaxct.com - Reg. No. 1998/024537/07

Premier Soccer League Runners Up 2004 - 2007 - 2011 Telkom Knockout Champions 2008 Telkom Knockout Finalist 2007 - 2009 Old Mutual Manganang Cup Champions 2007 - 2008 Rothmans Cup Champions 2000 Absa Cup Champions 2007 ABSA Cup Finalist 2003 MTN 8 Finalist 2009 BP Top 8 Finalist 2000 Iwisa Charity Spectacular 1999

Appendix B: REC approval Letter



APPROVED WITH STIPULATIONS REC Humanities New Application Form

19 June 2017

Project number: SPORT-2017-0162-121

Project title: The acute: chronic workload ratio and injury occurrence among elite South African male soccer players.

Dear Mr Ryan White

Your REC Humanities New Application Form received on 9 June 2017 was reviewed by the REC: Humanities and approved with stipulations.

Ethics approval period: 19 June 2017 - 18 June 2020

REC STIPULATIONS:

The researcher may proceed with the envisaged research provided that the following stipulations, relevant to the approval of the project are adhered to or addressed.

Some of these stipulations may require your response. Where a response is required, you must respond to the REC within **six (6) months** of the date of this letter. Your approval would expire automatically should your response not be received by the REC within 6 months of the date of this letter. If a response is required, please respond to the stipulations in a separate cover letter titled **"Response to REC stipulations"**.

REC Stipulations:

- 1) There are four typo mistakes in the Afrikaans informed consent form: Introduction (sal deel vorm), section 7 (studie deel te neem), section 9 (rakende die studie) and above signature of participant (was kans gegun).
- 2) With respect to giving permission for the use of 2016/2017 data in retrospect - is it not possible to get many of the players to give permission to use the already gathered data. Presumably many players are still at the club and others can be easily contacted? This is a suggestion rather than it must be done.
- 3) The REC concurs with the suggestion made by the DESC in the DESC report:

"DESC approval is for the 2017/2018 season's data; additional permission has been requested to use the data collected in 2016/2017 season, which was collected during standard data collection procedures by the coaching and training staff. Please provide a cover letter for the REC motivating the use of this data. The DESC did discuss this matter with the REC and if enough motivation is provided that the data was collected as part of standard operating procedures at the club and not for research purposes (plus permission from club to use the data) then it might be considered." [RESPONSE REQUIRED]

Please take note of the General Investigator Responsibilities attached to this letter. You may commence with your research after complying fully with these guidelines.

If the researcher deviates in any way from the proposal approved by the REC: Humanities, the researcher must notify the REC of these changes.

Please use your SU project number (SPORT-2017-0162-121) on any documents or correspondence with the REC concerning your project.

Please note that the REC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

FOR CONTINUATION OF PROJECTS AFTER REC APPROVAL PERIOD

Please note that a progress report should be submitted to the Research Ethics Committee: Humanities before the approval period has

expired if a continuation of ethics approval is required. The Committee will then consider the continuation of the project for a further year (if necessary)

Included Documents:

Document Type	File Name	Date	Version
Proof of permission	Picture1	14/05/2017	2
Research Protocol/Proposal	Final Protocol with Corrections for REC	07/06/2017	9
Informed Consent Form	Informed Consent Forms	07/06/2017	3
Information sheet	Information Sheet	07/06/2017	3

If you have any questions or need further help, please contact the REC office at cgraham@sun.ac.za.

Sincerely,

Clarissa Graham

REC Coordinator: Research Ethics Committee: Human Research (Humanities)

National Health Research Ethics Committee (NHREC) registration number: REC-050411-032.

The Research Ethics Committee: Humanities complies with the SA National Health Act No. 61 2003 as it pertains to health research. In addition, this committee abides by the ethical norms and principles for research established by the Declaration of Helsinki (2013) and the Department of Health Guidelines for Ethical Research: Principles Structures and Processes (2nd Ed.) 2015. Annually a number of projects may be selected randomly for an external audit.

Appendix C: REC cover letter

To Whom It May Concern,

I, Ryan White, the primary researcher of the study entitled “The acute: chronic workload ratio and injury occurrence among elite South African male soccer players.” would like to humbly request the use of retrospective data collected during the 2016/2017 PSL season. This data along with new data (to be collected) will provide a greater scope to the study and potentially enhance its results and usefulness to the scientific community as a whole as well as the greater soccer landscape in South Africa.

My motivation for this request includes:

1. The training load and injury data is collected already as part of the PSL FC standard operating procedures by coaches and staff.
2. Regardless of if permission is granted for use of this data the players would have done these processes regardless, and consented to the use of the data.
3. All of the procedures in place already at the PSL FC are the same as what the study will utilize and are standardized procedures. All of the players and staff are aware of how they work and what to do.
4. The additional analysis of this data will help to optimize training methods and prevent future injury, to which this data was originally meant. However, the PSL FC lacks the man power and expertise to do so.

I hope you take these reasons into consideration as I believe that there are many positive benefits for players, the club and South African sport as a whole as a study such as this is very far reaching in its usefulness.

Kind regards,
Ryan White.

Appendix D: information sheet (English version)



Department of Sport Science
Stellenbosch University
MATIELAND
7602

The acute: chronic workload ratio and injury occurrence among elite South African male soccer players.

Information Sheet

Purpose of the study: The purpose of study is to analyse training load utilizing sRPE and GPS metrics, in order to calculate the acute: chronic workload ratio and investigate the occurrence of injury. This will allow me to use this information to analyse injury risk, determine which variables best correlate with injury occurrence and explore if a relationship exists between internal and external training load.

Procedure: If you agree to participate in this study, the process of gathering the data required will be as per the current standard operating procedure of Ajax Cape Town FC. I would ask you to help with the following: *Global positioning system (GPS) data gathering, session rate of perceived exertion (sRPE) data gathering and injury occurrence data gathering.* Allow data to be gathered from you via GPS units for the entire duration of field training sessions and match-play during the pre- season and season. Each GPS unit will be held in place in the upper back region between the scapulae (shoulder-blades) by a padded neoprene harness provided by VXSport. This data will include heart rate information from during the sessions and matches. sRPE data will be recorded following training sessions, rehabilitation sessions and games. Lastly any injury data will be recorded in the event of an injury as per the standard operating procedure of the medical team (physios and doctors) and that of Ajax Cape Town FC.

Benefits: There is limited research surrounding training load monitoring and injury occurrences, especially in the South African context. This study will investigate these relationships and attempt to identify various factors that affect fatigue, performance and injuries. This will help to better educate coaches, sport scientists and medical staff to better understand training load and thus, potentially, decrease the risk of injury, alleviate unnecessary fatigue and increase performance!

Rights of Research Subjects: You can choose whether to be in this study or not. You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, please contact Ms Maléne Fouché at the Division for Research Development (**contact number:** [REDACTED] or [REDACTED]).

Rights of the Researcher: The researcher has the right to remove the subject from the research project should the subject fail to adhere to the instructions given during data collection.

Confidentiality: Any information about you that is obtained in connection with this study will remain confidential and will be disclosed only with your written permission. However, the results of the study may be published or disclosed to other people in a way that will not identify you. All data sets will be anonymous stored and analysed. No one, except the researcher, medical department and project supervisor will be able to access these raw data.

Consent: The researcher's intent is to only include subjects that freely choose to participate in this study. The participation is voluntary and you are free to withdraw your consent and discontinue with your participation at any time for any reason and you do not need to justify your decision. If you do withdraw we may wish to retain the data that we have recorded from you but only if you agree, otherwise your records will be destroyed. Your participation in the study is

voluntary and does not prejudice any right to compensation, which you may have under statute law.

Further Information: If you have any questions regarding this study you can contact any of the researchers detailed below. You will be given a copy of this information sheet and a consent form to read and keep prior to indicating your consent to participate by signing the consent form.

Student:	Ryan White	Study Leader:	Dr. H.W. Grobbelaar
E-Mail:	██████████	Email:	██████████
Tel. Number:	██████████	Tel. Number:	██████████
Co-Study Leader:	Simon De Waal		
E-Mail:	██████████		
Tel. Number:	██████████		

The Human Research Ethics Committee at the Stellenbosch University requires that all participants are informed that, if they have any complaint regarding the manner, in which a research project is conducted, it may be given to the researcher or, alternatively to the Administrative Officer, Human Research Ethics Committee, Division of Research Development, Stellenbosch University, Private Bag X1, Matieland, 7602.

Appendix E: information sheet (Afrikaans version)



Department of Sport Science
Stellenbosch University
MATIELAND
7602

The acute: chronic workload ratio and injury occurrence among elite South African male soccer players.

Inligtingsblad

Doel van die studie: Die doel van die studie is om die werkslading te analiseer, gekry deur die gebruik van sRPE en GPS, om die akute:chroniese verhouding te bepaal asook om die voorkoms van beserings te bepaal. Dit sal my instaat stel om die risiko van besering te bepaal, watter veranderlikes die beste korreleer met besering frekwensie en om te bepaal wat die verhouding is tussen interne en eksterne werkslading.

Prosedure: As u toestem om aan die studie deel te neem, gaan die proses van data kolleksie per die standaard operasie metodes van Ajax Cape Town FC wees. Ek gaan u vra om my te help met die volgende: *Global positioning system (GPS) data versameling, session rate of perceived exertion (sRPE) data versameling, asook die versameling van besering frekwensie data.* Toelating dat data vanaf u verkry word via GPS-eenhede vir die hele veld oefen sessie(s) en alle wedstryde wat in die voor-en in seisoen gespeel word. Elke GPS-eenheid sal op die bo-rug, tussen die scapula, geplaas word met 'n gevulde neoprene harnas wat voorsien word deur VXSport. Die data sal die hartklop informasie van die oefen sessies en wedstryde bevat. sRPE data sal tydens die oefen sessies, rehabilitasie sessies en wedstryde opgeneem word. Laastens, enige besering sal opgeneem word in lyn met die operasie prosedure van die mediese span, asook dit van Ajax Cape Town FC.

Voordele: Daar is beperkte navorsing gedoen rakende die werkslading monitering en besering voorkoms, veral in 'n Suid Afrikaanse konteks. Die studie sal die verhouding tussen verskeie faktore ondersoek wat moegheid, prestasie en beserings beïnvloed. Dit sal help om alle afrigters, sportwetenskaplikes en mediese personeel op te voed oor die belangrikheid van werkslading, wat moontlik kan lei tot 'n afname in beserings en moegheid en 'n toename in prestasie.

Regte van die deelnemer: U het die keuse om aan die studie deel te neem of nie. U mag van die studie onttrek op enige tyd, sonder enige boetes. U verwerp nie enige regseise, regte of remedies as gevolg van u deelname aan hierdie navorsings studie nie. As u enige vrae het rakende die studie, kontak asseblief mev. Maléne Fouché by die Department van Navorsing en Ontwikkeling (**kontaknommer: [REDACTED] of [REDACTED]**).

Regte van die navorser: Die navorser behou die reg om enige deelnemer van die studie te onttrek, as die deelnemer nie aan die prosedure van data versameling voldoen nie..

Vertroulikheid: Enige informasie wat tydens die studie verkry is, sal vertroulik bly en sal slegs met skriftelike toestemming openbaar gemaak word. Die relutante, van die studie, mag wel gepuliseer en openbaar gemaak word op so 'n manier wat u nie sal identifiseer nie. Alle data opnames sal anonym gestoor en ontleed word. Geen persoon behalwe die navorser, mediese personeel en projek toesighouer sal toegang hê tot die rou data.

Toestemming: Die navorser se voorneme is om slegs die individue in te sluit wat vrywilliglik aan die studie sal deelneem. Deelname is vrywillig en u is vry om op enige tyd van die studie te onttrek, sonder om u besluit te regverdig. As u wel besluit om van die studie te onttrek, versoek ons dat ons die data, wat van u verkry is, te behou, maar as u nie toestemming gee nie sal die data vernietig word. U deelname in die studie is vrywillig U deelname aan die studie is vrywillig en benadeel geen reg op vergoeding wat u volgens die wet kan hê nie

Verdere inligting: As u enige vrae rakende die studie het, kan u enige van die onderstaande navorsers kontak. U sal 'n kopie van die inligtingsblad en vrywaringsvorm gegee word om te lees en hou voor die aanduiding van u toestemming om deel te neem deur die vrywaringsvorm te onderteken.

Student:	Ryan White	Studieleier:	Dr. H.W. Grobbelaar
Epos:	██████████	Epos:	██████████
Tel. Nommer:	██████████	Tel. Nommer:	██████████

Mede-studieleier:	Simon De Waal
Epos:	██████████
Tel. Nommer:	██████████

(This part you should get from the Human Research Ethics Committee's website or something) The Human Research Ethics Committee at the Stellenbosch University requires that all participants are informed that, if they have any complaint regarding the manner, in which a research project is conducted, it may be given to the researcher or, alternatively to the Administrative Officer, Human Research Ethics Committee, Division of Research Development, Stellenbosch University, Private Bag X1, Matieland, 7602.

Appendix F: informed consent form (English version)



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STELLENBOSCH UNIVERSITY CONSENT TO PARTICIPATE IN RESEARCH

The acute: chronic workload ratio and injury occurrence among elite South African male soccer players.

You are invited to participate in a research study conducted by me, Ryan White (MSc Sport Science student) from the Department of Sport Science at Stellenbosch University. The results obtained from the study will contribute to the thesis for my Master's degree. You were selected as a possible participant in this study because you are a senior elite male soccer player currently playing for Ajax Cape Town FC.

1. PURPOSE OF THE STUDY

The purpose of study is to analyse training load utilizing sRPE and GPS metrics, in order to calculate the acute: chronic workload ratio and investigate the occurrence of injury. This will allow me to use this information to analyse injury risk, determine which variables best correlate with injury occurrence and explore if a relationship exists between internal and external training load.

2. PROCEDURES

If you agree to participate in this study, the process of gathering the data required will be as per the current standard operating procedure of Ajax Cape Town FC. I would ask you to help with the following: *Global positioning system (GPS) data gathering, session rate of perceived exertion (sRPE) data gathering and injury occurrence data gathering.* Allow data to be gathered from you via GPS units for

the entire duration of field training sessions and match-play during the pre-season and season. Each GPS unit will be held in place in the upper back region between the scapulae (shoulder-blades) by a padded neoprene harness provided by VXSport. This data will include heart rate information from during the sessions and matches. sRPE data will be recorded following training sessions, rehab sessions and games. Lastly any injury data will be recorded in the event of an injury as per the standard operating procedure of the medical team (physios and doctors) and that of Ajax Cape Town FC.

3. POTENTIAL RISKS AND DISCOMFORTS

There is no potential health or medical risks involved with participating in the study. There are no discomforts associated with the data gathering methods used. The GPS units enclosed in neoprene vests should not cause discomfort due to their small size. The sRPE will be collected as usual and is non-invasive in nature and is quick and convenient. Injury data collection will be conducted as normal and will require no additional effort or time from an injured player. The data that will be collected will only be used to monitor load and fatigue during training and matches. It will not affect your chances to be selected for the team.

4. POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

You will not benefit directly from the study. The study will benefit science and the sporting society. The results will provide coaches with the necessary knowledge to provide players on the professional level with better periodization programs and training loads specific to each individual player in the squad. This will allow for optimal performance through improved conditioning techniques and knowledge of fatigue and recovery. The study hopes to decrease the risk of injury, decrease fatigue and keep you playing and training at the highest physical level.

5. PAYMENT FOR PARTICIPATION

There will be no payment issued for participation in this study.

6. CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Confidentiality will be maintained by means of

storing data on a password-protected personal computer. Only the researcher, study leader and medical team including the gatekeeper (Head of Medical and Performance) will have access to the data. The data will remain anonymous at all times. If the research paper is published, the data will be reported for the group as a whole.

7. PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may also refuse to answer any questions you don't want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so. A participant may be withdrawn from this research if circumstances arise that warrant doing so.

8. IDENTIFICATION OF INVESTIGATORS

If you have any questions or concerns about the research, please feel free to contact:

<u>Name</u>	<u>Contact number</u>	<u>Email address</u>
Ryan White (Primary Investigator)	██████████	██████████
Dr. H.W. Grobbelaar (Study Leader from the Department of Sport Science)	██████████ ██████████	██████████
Simon De Waal (Co-Study Leader from the Department of Sport Science)	██████████	██████████

9. RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, contact Ms Maléne Fouché [██████████; ██████████
██████████] at the Division for Research Development.

SIGNATURE OF RESEARCH PARTICIPANT

The information above was described to me by Ryan White in English and I am in command of this language. I was given the opportunity to ask questions and these questions were answered to my satisfaction.

I hereby consent voluntarily to participate in this study.

Name of Participant

Signature of Participant

Date

SIGNATURE OF INVESTIGATOR

I declare that I explained the information given in this document to:

He was encouraged and given ample time to ask me any questions. This conversation was conducted in English.

Signature of Investigator

Date

Appendix G: informed consent form (Afrikaans version)



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UNIVERSITEIT VAN STELLENBOSCH TOESTEMMING OM AAN NARVORSING DEEL TE NEEM

The Acute: Chronic Workload Ratio and Injury Occurrence Among Elite South African Male Soccer Players.

U is uitgenooi om aan die studie deel te neem wat deur my, Ryan White (MSc Sportwetenskaplik student) van die Departement van Sportwetenskap by die Universiteit van Stellenbosch, uitgevoer word. Die resultate verkry tydens die studies al deel vorm van my meesters projek. U is gekies as 'n moontlike deelnemer, want u is 'n senior manlike elite sokker speler wat huidiglik by Ajax Cape Town FC speel.

1. DOEL VAN DIE STUDIE

Die doel van die studie is om die sRPE en GPS statistieke te gebruik om die akute:chroniese werkslading uit te werk, asook om die besering gevalle te analiseer. Dit sal my instaat stel om die inligting te gebruik om beserings potensiaal te bereken, analiseer watter veranderlikes die beste korreleer met besering gevalle, asook om te bereken of daar 'n verhouding bestaan tussen die interne- en eksterne werkslading.

2. PROSEDURES

As u instem om aan die studie deel gaan die inligting inneem proses die wees van Ajax Cape Town FC se standaard prosedures. Ek vra van u om my met die volgende te help: *Global positioning system (GPS) data insameling, session rate*

of perceived exertion (sRPE) data insameling en besering geval data insameling. Toestemming gee om data van u te verkry deur die GPS eenhede vir die hele veld oefensessie, asook alle voorseisoen en inseisoen wedstryde. Elke GPS-eenheid sal op die borug, tussen die vlerkies geplaas word, met'n gevulde neoprene harnas wat voorsien word deur VXSport. Die data sal die hartklop informasie van die oefen sessies en wedstryde bevat. sRPE data sal tydens die oefen sessies, rehabilitasie sessies en wedstryde opgeneem word. Laastens, enige besering sal opgeneem word in lyn met die operasie prosedure van die mediese span, asook dit van Ajax Cape Town FC.

3. POTENSIËLE RISIKO EN ONGEMAK

Daar sal geen potensiële gesondheids of mediese risiko wees tydens deelname aan die studie. Daar sal geen ongemak wees tydens data versameling. Die GPS eenhede, in die gevulde neoprene harnas, sal geen ongemak veroorsaak nie, vanwee hul klein grootte. Die sRPE data versameling metode volg 'n nie-indringende metode en is vining om in te samel. Besering data insameling sal geen addisionele moeite of tyd van die speler vereis nie.

Die data sal slegs gebruik word om werkslading en moegheid te bereken. Dit gaan geen span en speler seleksie beïnvloed nie.

4. POTENSIËLE VOORDELE VIR DIE DEELNEMER EN GEMEENSAP

U sal nie direk voordeel uit die studie trek nie. Die studie sal wetenskap en die sport gemeenskap bevoordeel. Die inligting sal afrigters help om, met die nodige kennis, spelers op professionele vlak met beter periodisering te voorsien, asook om die de opgestelde oefenprogramme te individualiseer. Dit sal moontlik lei tot optimale prestasie deur verbeterde kondisionering tegnieke en kennis van moegheid en herstelwerk. Die hoop van die studie is om die risiko en moegheid te verlaag, asook om spelers te help om op hul beste te oefen en speel.

5. BETALING VIR DEELNAME

Daar sal geen betaling wees vir die deelname aan die studie nie.

6. VERTROUOLIKHEID

Enige informasie wat tydens die studie verkry is, soek dit wat u kan identifiseer, sal anoniem bly en sal slegs met geskrewe toestemming openbaar gemaak word of soos wat die wet vereis. Betroulikheid sal behou word deur die gebruik van 'n wagwoord persoonlike rekenaar om al die data te stoor. Slegs die navorser, studieleiers en mediese personeel sal toegang tot die inligting hê. Die data sal teen alle tye anoniem bly.

As die studie gepubliseer word, sal die data as deel van 'n heel uitgewys word.

7. DEELNAME EN ONTTREKING

U kan kies om aan die studie deel te neem of nie. As u wel instem om aan die studiedeel te neem, mag u op enige tyd van die studie onttrek sonder enige nagevolge. U mag weier om enige vrae te antwoord en nogsteeds aan die studie deelneem. Die navorser mag u van die studie onttrek indien omstandighede bestaan wat dit regverdig.

8. UITKENNING VAN NAVORSERS

Indien u enige vrae oor die studie het, is u welkom om enige van die navorsers te kontak:

<u>Naam</u>	<u>Kontak nommer</u>	<u>Epos adres</u>
Ryan White (Primêre Navorser)	██████████	██████████
Dr. H.W. Grobbelaar (Studieleier van die Departement Sportwetenskap)	██████████ ██████████	██████████
Simon De Waal (Mede-studieleier van die Departement Sportwetenskap)	██████████	██████████

9. REGTE VAN DIE DEELNEMERS

U mag van die studie onttrek op enige tyd, sonder enige boetes. U verwerp nie enige regseise, regte of remedies as gevolg van u deelname aan hierdie navorsingstudie nie. As u enige vrae het rakende die studie, kontak asseblief mev. Maléne Fouché by die Department van Navorsing en Ontwikkeling (**kontak nommer: [REDACTED] of [REDACTED]**).

HANDTEKENING VAN DIE DEELNEMER

Die bostaande inligting is vir my verduidelik is deur Ryan White in Afrikaans en ek is beheer van die taal. Ek was kan gegun om vrae te vra en die vrae was tot my tevredenheid beantwoord.

Hiermee gee ek toestemming om vrywilliglik aan die studie deel te neem.

Naam van die deelnemer

Handtekening van die deelnemer

Datum

HANDTEKENING VAN DIE NAVORSER

Ek verklaar dat alle inligting in die dokument verduidelik is aan:

Hy was genoeg tyd gegun om vrae aan my te vra. Die gesprek was in Afrikaans uitgevoer.

Handtekening van die Navorser

Datum