NORWEGIAN SCHOOL OF SPORT SCIENCES

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The association between acute:chronic workload ratio and risk of injuries among elite youth football players

A 15-week prospective cohort study

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Department of Physical Performance
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Preface

So, this is it, the end of the master thesis journey. I have been a student for over 10 years but enjoy it now more than ever (except of being broke all the time). There is something that is extremely satisfying with exploring and learning new things.

Firstly, I would like to thank my supervisors Torstein Dalen and Matthew Spencer. Torstein; Thank you for including me in your first PhD project. Despite being busy with two jobs, bench pressing and now, even a family, you've always had time for a meeting and answering all of my emails! Matt; thank you for agreeing to supervise my master's thesis on a short notice. Receiving guidance and feedback by someone with your level of expertise has meant a lot! I would also like to thank my co-workers from the data collection process of the study, Markus Vagle and Kevin Nordanger.

To my mother and brother, family and friends and lastly, but most importantly, to my love Silje that had to put up with me for the last 12 years. You have always supported and encouraged me through these years. You are the most beautiful person I know, and I love you with all my heart.

Michael Kleppen,

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Abstract

A high injury rate has been reported in elite youth football. Injuries can have detrimental consequences for the youth elite athlete, not only interrupting their personal and team chances of success, but also as a potential burden later in life. An important part of reducing risk of injury in football is understanding the risk factors that may predispose the athletes to an injury. Training load (TL) has received increased attention as an important modifiable risk factor for injury in football and a growing level of research has investigated the training load-injury relationship using the acute:chronic workload ratio (ACWR) in adult elite football. However, research in youth elite football is scarce and the purpose of this master thesis was to investigate TL as a risk factor for injury, using the ACWR-method.

A cohort of male and female elite youth football players (n=86) were followed prospectively for a study period of 15 weeks. A self-reporting surveillance method, using a text message-based system was used to collect information on daily training load and injury. TL for all football related activity (match and training) was registered using the session-RPE (sRPE) and injury was registered according to an *all complaints* definition. For the ACWR analysis, TL-data was categorised based on z-scores and "traditional"-values. The ACWR was analysed as one-week acute load divided by four last week chronic (1:4 week) rolling averages and "Exponentially weighted moving averages" (EWMA) method for both of the TL categories.

An incidence rate of 15.9 injuries per 1000 hours of exposure was found when using an *all complaints* definition. Alternatively, when classifying injuries according to *time loss* definition, incidence rate was 4.7 injuries per 1000 hours of exposure. An increased risk of injury was found for players with a high ACWR compared to medium and a low ACWR. A low ACWR did not have a different risk compared to medium ACWR.

Contents

1. Introduction

Football is the most popular sport in the world with men and woman of all ages and level of expertise participating. A survey conducted in 2006 by the International Federation of Association Football (FIFA) estimated that over 265 million players were participating in football worldwide. Furthermore, 38 million were registered players with most being younger than 18 years of age (FIFA, 2007). In Norway, football is the most popular organized sport, with more than 1751 different clubs. The Football Association of Norway (NFF) have more than 375 000 registered players, where 102 250 players are in the age group 13-19 years old (*Norges Idrettsforbund*, 2014).

For the youth and adolescent population, participation in organised sports is essential for healthy growth and development. Football is multifaceted game, with exercise training improving cardiovascular, metabolic and musculoskeletal fitness, while also inducing beneficial effects on health risk factors (Faude, Rößler, & Junge, 2013; Milanović et al., 2018). While the health benefits of participating in football are considerable, it also increases the risk of sustaining health problems such as injuries and illnesses (Schwellnus et al., 2016; Watson, Brickson, Brooks, & Dunn, 2016). For youth athletes, health problems may have catastrophic outcome, not only interrupting training and competition, but in worst case ending physical activity and sport participation (A. Murray, 2017).

A particular vulnerable group with regards to health problems is the elite youth population striving to become professionals (Brink, Visscher, et al., 2010). Elite youth footballers must engage in large amounts of training to improve performance, however this may increase the risk of early burnout, injury and illnesses (Bergeron et al., 2015; Brink, Nederhof, Visscher, Schmikli, & Lemmink, 2010).

Training load has received increased attention as an important modifiable risk factor for injury in team sports and a growing level of research is focused on the relationship between training load and injury incidence in football (McCall, Dupont, & Ekstrand, 2018; Soligard et al., 2016). However, most research has investigated elite adult football players, and little exists on the elite youth population.

1.1 Purpose of the study

Based on shortcomings in the available literature, the purpose of this study was to investigate the relationship between training load and injury incidence in a cohort of Norwegian elite youth football players. Findings from this study may increase our understanding of the injury extent in youth elite football and give us a more profound understanding of training load as a risk factor for injuries on football. Furthermore, this knowledge can improve the process of risk management in youth elite football, which is the overall process of identifying, assessing, and controlling risks. This process is not possible without quantifying the incidence and severity of injuries, as well as associated risk factors and mechanisms.

1.1.1 Research objectives

The aim of the present study was to (1) Investigate injury incidence in a cohort of youth elite football players and (2) Investigate the relationship between TL and injury incidence using the ACWR-method.

2. Theory

2.1 Elite football

2.1.1 Demands of the game

Elite sport performance requires the integration of multiple physiological, biomechanical and psychological factors within the constraints of competition regulations and under the prevailing environmental conditions (Hawley, Lundby, Cotter, & Burke, 2018). Football is a high intensity intermittent team sport where performance is dependent on a complex interaction between technical, tactical, physical, physiological and mental factors (Stølen, Chamari, Castagna, & Wisløff, 2005). The performance requirements increase with the level of play and professional football has changed dramatically from previous decades, evolving into a faster, more intensive and technical game. Modern elite players are covering greater distance, undertaking more explosive movements and competing at higher intensities than before. In the English Premier League, high-intensity running, and sprint distance have increased by 30-50%, while the overall number of passes have increased by 40% across seven seasons (Barnes, Archer, Hogg, Bush, & Bradley, 2014). The high demand of elite football is exposing the athletes to a very high training- and competition load. The Union of European Football Associations (UEFA) has expressed its concern over the physical and mental load on professional footballers and the possible risk of injury as a result of such loads (Ekstrand, Hägglund, & Waldén, 2011).

2.1.2 The transition from youth to elite adult football

With the increasing performance demands in elite adult football, the elite youth athletes must work harder than ever to reach top professional level. Many young players dream of one day becoming professional, but with football increasing in popularity and the relatively limited opportunities to a gain professional contract results in tough competition to reach professional level (Haugaasen & Jordet, 2012). To reach their goal many young athletes start specialization at an early age, exposing themselves to high training volume and frequent competitions (Rosen, Frohm, Kottorp, Friden, & Heijne, 2017). In football there is relatively solid evidence for the importance of participating in large amounts of football-specific practice to reach elite youth and senior levels (Haugaasen, Toering, & Jordet, 2014). Although exposure to high training volume of football is very important for the youth elite athlete, an insufficient balance between training load and recovery can lead to decreased tissue health and potential injuries (Soligard et al., 2016). The adolescent years are also a period of high, non-sport related stress such as family and academic commitments (Bourdon et al., 2017). The physical stress of high training load, alongside increased psychosocial stress such as pressure from coach and parents may further increase risk of injury and illness within this population (Brink, Visscher, et al., 2010).

To make sure youth athletes that are aspiring for elite level football are staying healthy, capable and resilient they must be exposed to high quality training and high TL, but with adequate recovery to avoid overreaching and potential health problems. Football players could have as much as 20 years of development before reaching their peak performance age (Haugaasen & Jordet, 2012). Long term monitoring, careful planning and management of training load is fundamental to guarantee a long sporting career (Bourdon et al., 2017). To be able to control and adjust the TL and recovery we need to monitor the athletes (Roald Bahr, 2014). Furthermore, monitoring is fundamental to understanding the relationship between training load – performance and risk of injury (Soligard et al., 2016).

2.2 Training Load

2.2.1 Defining Load

In 2015 the International Olympic committee convened a consensus meeting on load and health outcomes in sports. In the consensus statement the term load was defined as "The sport and non-sport burden as a stimulus that is applied to a human biological system. The stimulus can be applied over varying time and with varying magnitude" (Soligard et al., 2016). In sports medicine and exercise physiology, the term load should therefore be seen as a broad term including physical, psychological and social factors. Furthermore, the physical load from training and match can be referred to as training load (TL), which can be defined as "the cumulative stress placed on an individual from multiple training sessions and games over a period of time" (Gabbett, Whyte, Hartwig, Wescombe, & Naughton, 2014).

2.2.2 Training load measures

A range of different measures can be used to quantify TL and is usually categorised as either internal- or external load. External load is the work performed by the athlete during training or competition, while the internal load is the relative biological (physiological and psychological) responses to the work performed. Furthermore, TL can be described in absolute or relative terms. Relative load is the external or internal *rate* of load application placed on the athlete, while *absolute* load is the external or internal total load irrespective of the rate of load application or load history (M. K. Drew & Finch, 2016; Soligard et al., 2016).

Quantification of external TL has typically been done using objective markers such as hours, duration and distance. However, the use of microtechnology in sports has grown in popularity, giving an even more detailed description of external TL. Equipment such as global positioning system (GPS) provides information on speed and distances covered, while inertial sensors such as accelerometers and gyroscopes embedded in the devices also provide information on non-locomotor sport-specific activities (e.g. jumps, collisions, throwing motions)(Gabbett, 2016). Internal TL on the other hand, can be quantified using both objective and subjective measures, using measures such as heart rate monitoring (HR) and rating of perceived exertion (RPE) respectively. HR-monitoring is the most common objective marker, measuring the relative internal TL placed on the athlete. It has the advantage of monitoring internal TL in “real time” during activity. The RPE-scale is a subjective measurement of internal TL, which is considered a global measure of perceived intensity (Borg, 1982).

2.2.3 Selecting appropriate measures

While TL-measures can be general, such as time or distance, a sports specific and individual approach is often needed as each sport has distinct movement patterns and physiological demands (Thornton, Delaney, Duthie, & Dascombe, 2017). The use of technology to measure TL has broaden the understanding of player- and position specific demands in football. Especially in the elite setting, the use of technology such as GPS- and inertial sensors has become an integral part of load monitoring and sport performance analysis (Chambers, Gabbett, Cole, & Beard, 2015). With increasingly advanced technologies becoming available there is a continuous pursuit of the best methodologies to capture and interpret data (Bourdon et al., 2017; Gabbett & Whiteley, 2017). However, most youth football teams don’t have the recourses to invest in expensive technological solutions and must use alternative methods. The session-RPE (sRPE) method has shown to be a valid and reliable tool to measure TL across a wide range of exercise modes and activities such as strength training, endurance training and team sports including football (Day, McGuigan, Brice, & Foster, 2004; Foster et al., 2001; Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004; Lupo, Tessitore, Gasperi, & Gomez, 2017). The sRPE is calculated by multiplying the duration of the session (min) with the individual RPE using a modified Borgs scale, 1-10 scale and expressed as "arbitrary units" (Foster et al., 2001; Gabbett, 2016).

Despite numerous methods to monitor TL, the validity of some markers of adaption and maladaptation to load are limited (Soligard et al., 2016). Furthermore, there is a range of different practices used when monitoring TL in sports and a lack of agreement on the optimal method to do so (Gabbett et al., 2017). When selecting an instrument for monitoring TL, consideration must be made to what specific goals the monitoring have and which specific measures to collect, as well as logistical and financial cost (Windt & Gabbett, 2017).

2.2.4 Purpose of monitoring training load

Training involves the manipulation of the variable's intensity, duration and frequency and TL monitoring is the process of recording and quantifying these variables (Smith, 2003). In elite football the general goal is to perform at the highest-level during competition. To achieve this, the team and players must engage in systematic training within a long-term development plan to maximize positive training adaptations while minimizing the risk of sustaining injury. The specific purpose of monitoring TL can vary depending on perspective of the practitioner, such as the coach, physical trainer or medical staff. However, a common objective is to increase performance while at the same time reducing risk of burnout and health problems (Bourdon et al., 2017; Gabbett, 2016) .

Monitoring TL on an individual level is important as athletes can execute the same type of sessions (external TL) on different occasions but experience different internal responses depending on factors such as fatigue, emotional stress or injury and illness (Bourdon et al., 2017). Furthermore, individual monitoring can provide an assessment of an athlete's capacity to handle a training session delivered and obtain data in "real-time" to ensure athletes are meeting planned performance targets. For the injured athlete, TL monitoring can assist in planning a safe return to play (Gabbett, 2016).

Considering the individual TL response is particular important in team sports where training is typically planned using external parameters and mostly occurs as a collective. Several studies in football have shown a mismatch between the coaches and the players perception of effort (Brink, Frencken, Jordet, & Lemmink, 2014; Brink, Kersten, & Frencken, 2017). Monitoring TL can assist the coach in training planning as well as decision making on player availability for training and competition (Bourdon et al., 2017).

Monitoring TL can assist in optimising the training response and need for recovery on both an individual and a team level. Furthermore, the monitoring process can help inform the planning and modification of training programmes and competition calendars. Monitoring TL is a fundamental part of understanding the relationship between TL-fitness and TL-injury (Soligard et al., 2016).

2.3 Injuries in youth football

Football is one of the team sports with the highest rate of sports injuries per player. Injury incidence in youth football has increased over the last decade and is now similar to injury problems in adult football (Kolstrup, Koopmann, Nygaard, Nygaard, & Agger, 2016; Nilsson, Östenberg, & Alricsson, 2016). Several epidemiological studies have been conducted to investigate the extent of injuries in youth football, but the exact scope of the problem is somewhat unclear. Concerns have been raised with regards to large inconsistency in the methodology between studies as a variety of definitions and recording methods has influenced the rate of injury reported, making interstudy comparison difficult (Roald Bahr, 2009; Fuller et al., 2006).

2.3.1 Injury definitions and surveillance methods

In general terms, a "sports injury" is a collective name for all types of damage that can occur in relation to sporting activities, but the type and severity of the injury will vary. Defining what actually constitutes a "recordable event" is not that obvious and several consensus papers have been published on injury definition in multiple sports (Clarsen & Bahr, 2014; Van Mechelen, Hlobil, & Kemper, 1992).

A consensus statement on epidemiological research in football was published by Fuller et al. (2006) in the statement three different injury definitions were proposed; First, an *all complaints* definition, includes any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities. Second, a *time loss* injury, when a player can't take full part in training or match. Third, a *medical attention* injury, when a player receives assessment of medical conditioning by a qualified medical practitioner (Fuller et al., 2006).

In football, injuries are normally reported as injury incidence which is the numbers of sports injuries per exposure time, normally expressed per 1000 player hours (Fuller et al., 2006). However, research applying injury incidence as the outcome is highly dependent on the definition of both injury and participation, as well as the research design and methodology used (prospective vs retrospective) (Van Mechelen et al., 1992). Furthermore, the choice of injury definition would depend on factors such as duration of the study, resources available, type of injuries (acute vs overuse) and how data are collected (Clarsen & Bahr, 2014).

2.3.2 Choice of injury definition

The *time loss* injury definition is the most commonly used, as it is easy to identify the injury event increasing the reliability of the measure. However, it captures the fewest injuries and has shown to underestimate both overuse and acute conditions, as athletes often keep on training and competing despite of injury. Since *time loss* is the most commonly used definition it is possible that current injury data are only scratching the surface, showing the "worst cases" of injury problems in football (Roald Bahr, 2009; Clarsen & Bahr, 2014).

The *medical attention* definition captures a larger proportion of injuries, as receiving medical attention does not necessary lead to time loss. However, the *medical attention* definition is probably a less reliable method compared to *time loss* definition as medical support and practise vary between clubs and level of play (Clarsen & Bahr, 2014). Furthermore, lower leagues and youth teams may not have any medical personnel to collect data, making it impractical in many cases (McCunn, Sampson, Whalan, & Meyer, 2017).

A true *all complaints* definition captures most injuries as player's symptoms are the only criteria for being defined as an injury. However, individual experiences such as injury and pain tolerance will influence the number of injuries reported (Clarsen & Bahr, 2014).

2.3.3 Injury surveillance method

An obvious advantage of adopting an *all complaints* definition is that players can report their own symptoms using a self-reported surveillance method. Recording injuries according to *medical attention* is observer dependent and therefore a more time-and resource-intensive method that may not be feasible in many sporting environments (Moller et al., 2018). Individual self-reported registration through text messaging has shown to capture a larger proportion of injuries compared with *medical attention* (A Nilstad, Bahr, & Andersen, 2014). The Oslo Sports Trauma Research Centre (OSTRC) Overuse Injury Questionnaire is a self-reporting injury surveillance tool that was developed to address many of the limitations of observer reporting. The OSTRC Overuse Injury Questionnaire has been shown to identify injuries and physical complaints missed by traditional approaches, showing substantially higher prevalence of overuse injuries. Furthermore, it measures the consequences of injury based on self-reported participation and performance limitations rather than time loss (Clarsen, Myklebust, & Bahr, 2012; Clarsen, Rønsen, Myklebust, Flørenes, & Bahr, 2014; Harøy et al., 2017).

2.3.4 Injury incidence in youth football

In a systematic review by Faude et al. (2013) on football injuries among children and adolescent players in the age group of 13-19 years, they found an injury rate of 1-5 injuries per 1000 hours of training. Furthermore, incidence was increasing with age and approaching adult values at the age of 17-19 years. Match injury incidence was reported to be considerably higher, ranging between 15-20 injuries per 1000 match hours in players (Faude et al., 2013). In another systematic review, by Pfirrmann, Herbst, Ingelfinger, Simon, and Tug (2016) on injuries among male elite youth football players they reported a rate of 3.7 to 11.1 injuries per 1000 training hours and 9.5 to 48.8 injuries per 1000 match hours. Furthermore, they also found youth elite male players to have a higher injury incidence per training hours than professionals (Pfirrmann et al., 2016).

A few selected epidemiological studies on injury incidence in youth football are presented in table 1. All of the studies have a prospective design and only includes players in the age group of 15-19 years. The studies are presented according to study duration, study population and injury definition. Injuries are expressed as injuries per 1000 hours and divided into training, competition and total incidence, when available. In table 1, it is clear that most prospective studies are using a *time loss* definition, while studies investigating tournaments are preferring a *medical attention* definition. Only in the study by Clausen et al. (2014), a true *all complaints* definition was adopted. The ability of a true *all complaints* definition to capture more injuries is reflected in the high total incidence compared with the other studies. Furthermore, most studies are reporting both training- and match incidence, where match incidence is substantial higher. Incidence is also reported to be high during training camps and tournaments (table1).

Table 1: Overview of a selected group of studies that have investigated injury incidence among youth football players.

Study, Follow- up period	**Population**	**Injury recording, definition**	**Injury incidence per 1000 h**		
			Training	**Competition**	**Total**
Season activities					
Bianco et al. (2016) One season	Male Elite N = 23 17-19 years (older players in study)	Prospective, Time loss, medical attention	1.1	4.3	1.4
Brito et al. (2012) One season	Male sub-elite N = 161 17-18 years N= 165 15-16 years	Prospective, Time loss (more than 1 day absent), Injury recordings by medical or coaching staff	1.2 1.1	7.1 3.7	1.7 1.4
Clausen et al. (2014) One season	Female sub-elite N = 438 15-18 years	Prospective, Time loss and no time loss injuries, Self-reported questionnaire			15.3
Le Gall et al. (2008) Eight-seasons	Female Elite N = 119 15-19 years	Prospective, Time loss (more than 1 day absent), medical attention	4.6	22.4	6.4
Nielsen and Yde (1989) One outdoor season	Male N = 30 16-18 years	Prospective, Time loss, registered by coaches	3.6	14.4	
Nilsson et al. (2016) One season	Male Elite N = 43 15-19 years	Time loss, medical attention	5.6	15,5	6.8
Nogueira et al. (2017) Six-months	Male amateur N = 475 15-19 years	Prospective, Time loss, medical attention	2.1	14.2	3.9
Peterson et al. (2000) One year	Male (high level) N = 136 16-18 years	Prospective, All complaints, Medical attention	7.9	38.4	6.6
Training camps and tournaments					
Elias (2001) Tournaments in the period 1988-1997	Male and female N = not available Under 19	Prospective, Medical attention (presentation to Cup medical facility)		13.5 (male) 10.6 (female)	
Kolstrup et al. (2016) Three tournaments 2012-2014	Male and female N = not available 16-19 years	Prospective, All physical complaint, Medical attention (presentation to Cup medical facility)		13.8	
Schmidt-Olsen et.al (1985) Summer tournament	Male and female N = 1292 males N = 232 females 17-19 years	Medical attention (first-aid treatment)		20.6 (male) 47.2 (female)	

2.3.5 Injury aetiology

Injuries are thought to result from a complex interaction between multiple risk factors and events (R Bahr & Holme, 2003). Understanding the relationship between risk factors and sporting injuries is an important step in the process of developing injury prevention strategies (Van Mechelen et al., 1992). However, risk factors vary between individuals and between sports making injury prediction one of the most challenging issues in sports (Bittencourt et al., 2016). Several injury aetiology models have been proposed over the past two decades for the purpose of explaining the causes of sports injury (Roald Bahr & Krosshaug, 2005; Bittencourt et al., 2016; Meeuwisse, 1994; Meeuwisse, Tyreman, Hagel, & Emery, 2007; Windt & Gabbett, 2017).

Meeuwisse et al. (2007) proposed a dynamic model of aetiology in sports injury (Figure 1). In the model, the intrinsic risk factors are certain traits of the athlete that might predispose them to injuries. While some intrinsic factors such as strength and flexibility are considered modifiable, other factors such as age and previous injuries are considered non-modifiable. The "predisposed" athlete is then exposed to external risk factors such as playing surface and equipment which makes them susceptible to injury in case of an inciting event (Meeuwisse et al., 2007).

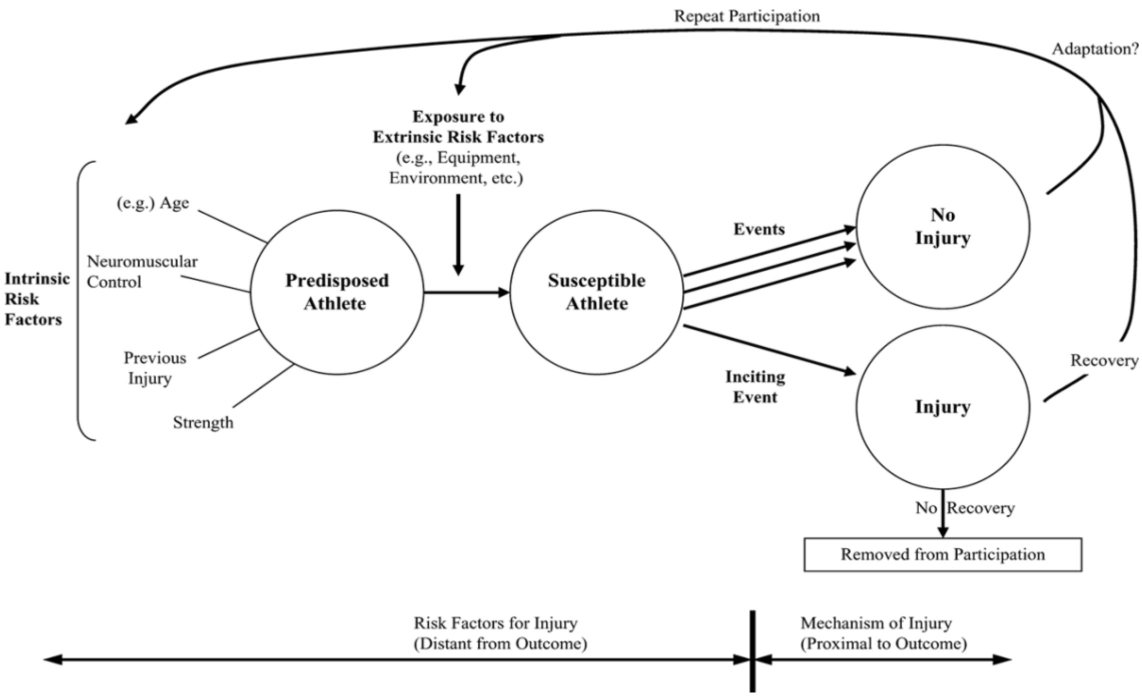

Figure 1: A dynamic model of aetiology in sport injury: The recursive nature of risk and causation. Meeuwisse et al., 2007, Clinical Journal of Sport Medicine, 17, p. 217. Copyright 2007 Clinical Journal of Sport Medicine.

The influence of the different intrinsic and external risk factors and their interaction will affect the type of injury that is sustained (Meeuwisse, 1994). The mechanism of an injury will most likely differ between an acute and an overload type of injury. Acute injuries are most often associated with a single definite trauma, while overload injuries are thought to be a result of repetitive micro trauma. Whereas acute contact injuries are considered mostly unavoidable, the non-contact soft tissue injuries are considered largely preventable (Bowen, Gross, Gimpel, & Li, 2016).

Despite attempts to model and understand the pathway leading to an injury there has been limited success in the field of injury prediction and prevention. Current aetiology models have recognized the complex nature of sports injuries, but also criticised for over simplicity and a reductionist view of injury aetiology (Hulme & Finch, 2015).

Bittencourt et al. (2016) recently introduced a new model for understanding sports injury aetiology. The model implements complex system thinking to address the dynamic and complex nature of sport injury aetiology. A complex system thinking approach focuses on understanding the functioning of the system as a whole where the effect of any given factor may depend on the state of other factors in the system by creating feedback loops and dependencies (Kroelinger et al., 2014). In the complex system injury model by Bittencourt et al. (2016) multiple risk factors interact with each other in an unpredictable way creating "risk patterns". It is assumed that different patterns or relations between the known risk factors can lead to same injury. As there are multiple pathways leading to a similar outcome, understanding the patterns of interaction are more important than finding single causes (Bittencourt et al., 2016). By integrating complex system thinking, this injury aetiology model is moving away from a linear paradigm of injury causality to a dynamic model where athletes susceptibility to injury is continually changing according to many adaptions or maladaptation's that occur with continued sports participation (Hulme & Finch, 2015).

2.3.6 Risk factors for injury in football

Injury aetiology is multifactorial and complex, however most studies have investigated single risk factors. In football, studies have found several intrinsic- and extrinsic risk factors that have been associated with injury. For modifiable intrinsic risk factors, movement skill, neuromuscular fatigue and body mass index (BMI) have been identified (Agnethe Nilstad, Andersen, Bahr, Holme, & Steffen, 2014; Read, Jimenez, Oliver, & Lloyd, 2018). For the non-modifiable intrinsic factors, age and previous injury are associated with the risk of sustaining injury (Arnason et al., 2004; Hägglund, Waldén, & Ekstrand, 2013). Extrinsic factors such as, which parts of the season and match location has been identified as risk factors (Hägglund et al., 2013). Furthermore, factors such as physical stress and psychosocial stress also seem to increase the injury risk (Brink, Visscher, et al., 2010; Ivarsson, Johnson, & Podlog, 2013)

TL has been reported as a modifiable risk factor for subsequent injury in football (Malone, Owen, et al., 2017). According to the UEFA Elite Club Injury Study (ECIS) on elite teams, internal training and match TL are one of the most important risk factors (McCall et al., 2018).

2.4 The training load- injury relationship

2.4.1 Training load- injury aetiology model

Every sport injury is sustained while an athlete is exposed to TL, but previous injury aetiology models have not taken the association between TL and injury into consideration. Windt and Gabbett (2017) recently proposed an updated injury aetiology model including TL as part of the causal chain leading to an injury (Figure 2).

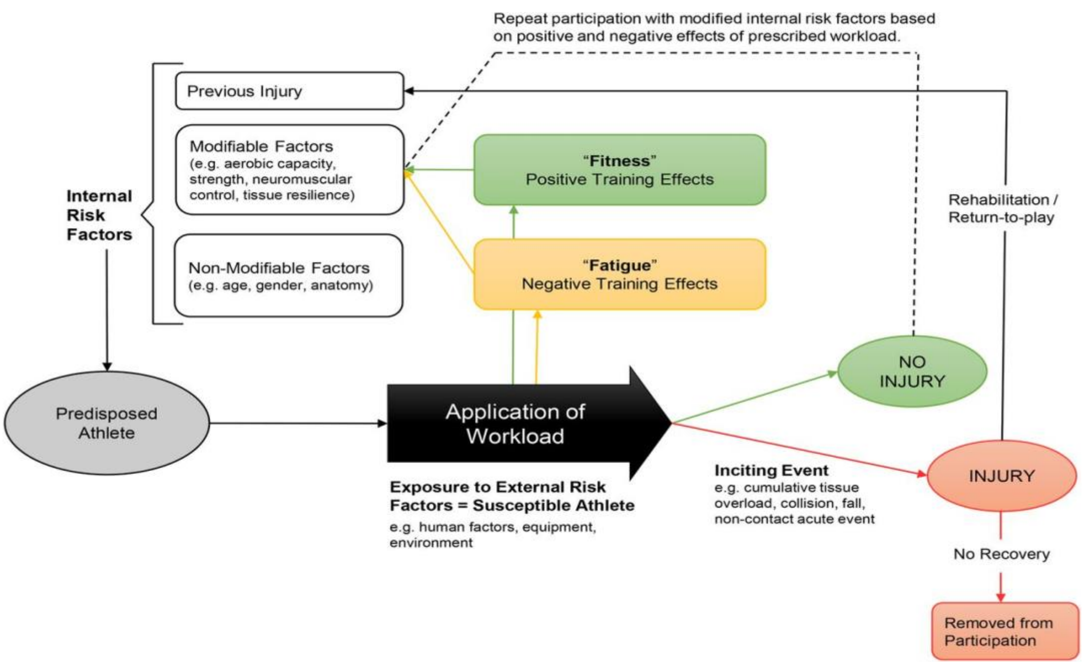

Figure 2: How do training and competition workloads relate to injury? The Workload-injury aetiology model: J. Windt & T. J. Gabbett, 2016, British Journal of Sports Medicine, 51(5), p. 433. Copyright 2016 British Journal of Sports Medicine.

In the model, TL is not thought of as either an intrinsic- or external risk factor per se, but rather a variable exposing the athlete to external risk factors and potentially inciting event. Furthermore, the application of TL through training and competition can affect the athletes modifiable internal risk factors through positive or negative physiological adaptions. The modifiable internal factors can be seen as the characteristics that make athletes more robust or more susceptible to injury at any given TL. Positive training effects such as high fitness may protect against injuries, while negative training effects such as fatigue or reduced neuromuscular control may heighten the risk (Read et al., 2018; Windt & Gabbett, 2017). The athlete's exposure to external risk factors are determined by total load, while the physiological adaption affecting the modifiable internal risk factors are not only dependent on total TL, but also the rate of the TL that is applied. Furthermore, if an injury would occur, the athlete would go through a rehabilitation phase while applying TL to restore fitness before returning to training and competition. In this way the application of TL through the rehabilitation phase would modify previous injury as an internal risk factor (Windt & Gabbett, 2017).

2.4.2 Training load and biological adaptation

Exercise can be seen as a "stressor" representing a major challenge to whole-body homeostasis. In an attempt to meet this challenge, acute and adaptive responses take place at the cellular levels and systematic levels to minimise these widespread disruptions (Hawley, Hargreaves, Joyner, & Zierath, 2014). A paramount principle in training theory is to use the process of biological adaptation induced by TL through training and competition to increase fitness and subsequently improve performance (Soligard et al., 2016). However, application of TL can also have negative consequences such as fatigue and biological maladaptation that potentially can result in injury.

In a simplistic way, the relationship between TL and biological adaptation can be explained as a balance between TL and recovery (figure 3). With adequate magnitude of TL and recovery, positive biological adaptation may occur, increasing the athlete's capacity to withstand TL. On the contrary, an insufficient balance between TL and recovery can lead to decreased tissue health and increase risk of injury (Soligard et al., 2016).

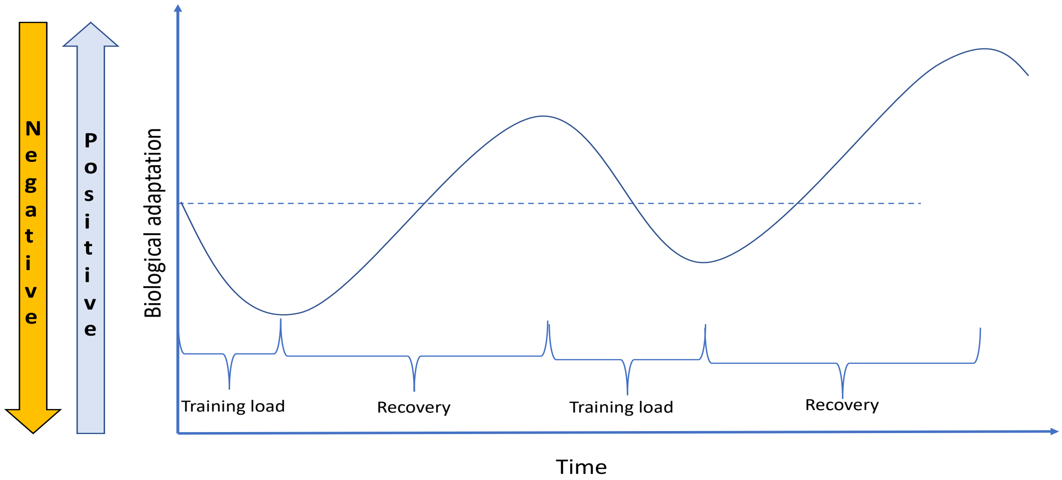

Figure 3: Biological adaptation, described as a balance between TL and recovery (adapted from Figure 1.in Soligard et al. 2016).

However, while the concept of a simple and predictable biological response is appealing the fitness response has shown hard to predict and to date, no single physiological marker has been identified that can measure the fitness and fatigue responses to exercise (Borresen & Lambert, 2009). There is still a lack of understanding on the relationship between load characteristics and non-contact injuries (Fanchini et al., 2018b). On a tissue level there are different physiological and biomechanical load-adaptation pathways as tissues have different response rates to load (Vanrenterghem, Nedergaard, Robinson, & Drust, 2017).

In the recent consensus paper, load was defined as "the sport and non-sport burden as stimulus that is applied to a human biological system" (Soligard et al., 2016). The broad definition of load gives a more holistic understanding of the load-fitness and load-injury relationship. With regards to injury it is important to acknowledge that maladaptation is not only triggered by poor management of training and competition loads, but also by interaction with psychological non-sport stressors, such as negative life-event stress and daily hassles (Ivarsson et al., 2013). Furthermore, the biological stress response to load should not be seen as generalized and non-specific, but highly individualized and context specific. A complex interaction of individual factors such as age, sex, genetics, nutrition, previous TL history and non-biological factors such as psycho-emotional influence training adaptations (figure 4) (Borresen & Lambert, 2009; Kiely, 2018).

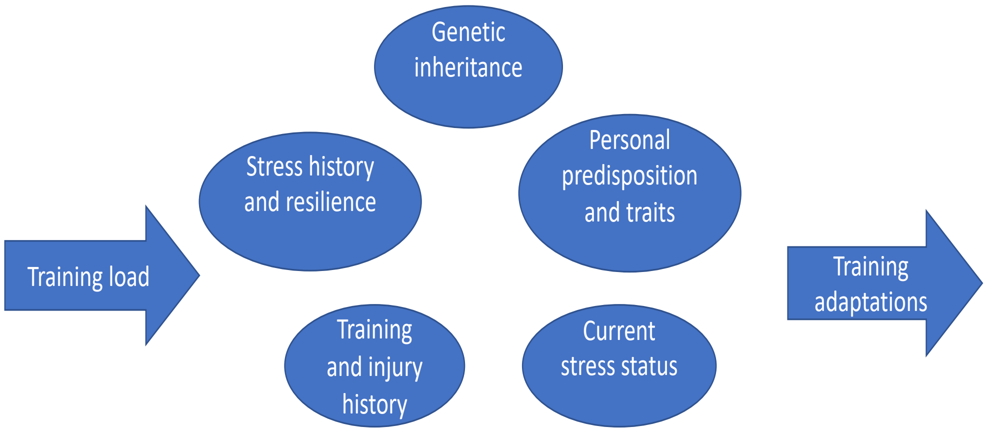

Figure 4: The set of adaptions launched in response to TL are modulated by many variables (adapted from figure 2. in Kiely et al. 2018).

2.4.3 Absolute training load and risk of injury

Higher training volumes have shown to increase the risk of overuse injury in multiple youth sports (DiFiori et al., 2014). High absolute training and/or competition load has also been identified as a risk factor for injuries in football (Soligard et al., 2016).

However, evidence is also showing that a high chronic absolute load can offer a protective effect against injuries (Gabbett, 2016). Studies have shown that team-sport athletes with well-developed physical qualities such as high body strength, repeated sprint abilities and speed have better tolerance to higher workloads and reduced risk of injury (Malone et al., 2018). For female football players, poor pre-season aerobic fitness increased risk of in season injury and illness (Watson et al., 2016). Building physical qualities through high chronic load training can make athletes more resilient to withstand the potential risk of high load (Malone, Roe, Doran, Gabbett, & Collins, 2017). The notion that high training load can increase risk of injury, but at the same time protect against injuries and has been termed the training-injury prevention paradox (Gabbett, 2016).

2.4.4 Relative training load and risk of injury

Through the evidence that chronic TL load may offer protection against injuries, it is unclear if it is the absolute load which is the most important factor. Multiple studies have shown that rapid changes in TL is associated with subsequent injury in elite professional sports such as cricket fast bowlers, rugby league, Australian rule football, basketball and football (Hulin et al., 2013; Hulin, Gabbett, Lawson, Caputi, & Sampson, 2016; Malone, Owen, et al., 2017; N. Murray, Gabbett, Townshend, Hulin, & McLellan, 2017; Weiss, Allen, McGuigan, & Whatman, 2017). It seems that when the athletes perform greater load than they are prepared for, they are more likely to become injured (Blanch & Gabbett, 2015). It is therefore probably more important to consider the individuals current TL and TL history than absolute TL alone (Gabbett & Whiteley, 2017).

2.4.5 The acute:chronic workload ratio

The ACWR has been described by Gabbett (2016) as a method to model the relationship between changes in load and risk of injury. The ACWR is based on Banisters fitness-fatigue model where chronic load dictates the athletes overall "fitness" while the acute load dictates the "fatigue" state of an athlete (Banister & Calvert, 1980). The ACWR-method suggests that the difference between an individual`s current TL, and the previous TL history is more useful as a predictor of injury than absolute load (Gabbett & Whiteley, 2017). The ACWR-method examines the longitudinal patterns of the monitored data, comparing the acute TL (usually of the last week) to the chronic TL(usually four-week rolling average) (Soligard et al., 2016). The ACWR can be seen as a dynamic representation of the athlete preparedness; comparing the load the athlete has performed (acute) relative to the load the athlete has prepared for (chronic) (Malone, Roe, et al., 2017).

Furthermore, Gabbett (2016) described the relationship between ACWR and injury as U-shaped (Figure 5). A ratio of 1.0 represents an equal load for the last week compared to what the athlete has prepared for over the past 4 weeks. A ratio of 0.5 would suggest a load that is only half as much as the athlete is prepared for, while 2.0 would suggest athlete has performed twice the load (Blanch & Gabbett, 2016). The lowest risk of injury seems to occur where the acute load is relative equal to the chronic load (ratio of 0.8-1.3). This ratio has been termed the "sweet spot" as it is associated with lower risk of injury. However, when the ACWR increases > 1.5, the risk if injury increases exponentially and has therefore been termed the “danger zone” (Bourdon et al., 2017). Besides its usefulness in managing load to reduce the risk of injury, the ACWR can also help practitioners in the process of safe return to sports training after an injury, as well as guiding coaches and athlete in the training planning to develop a high level of fitness (Blanch & Gabbett, 2016).

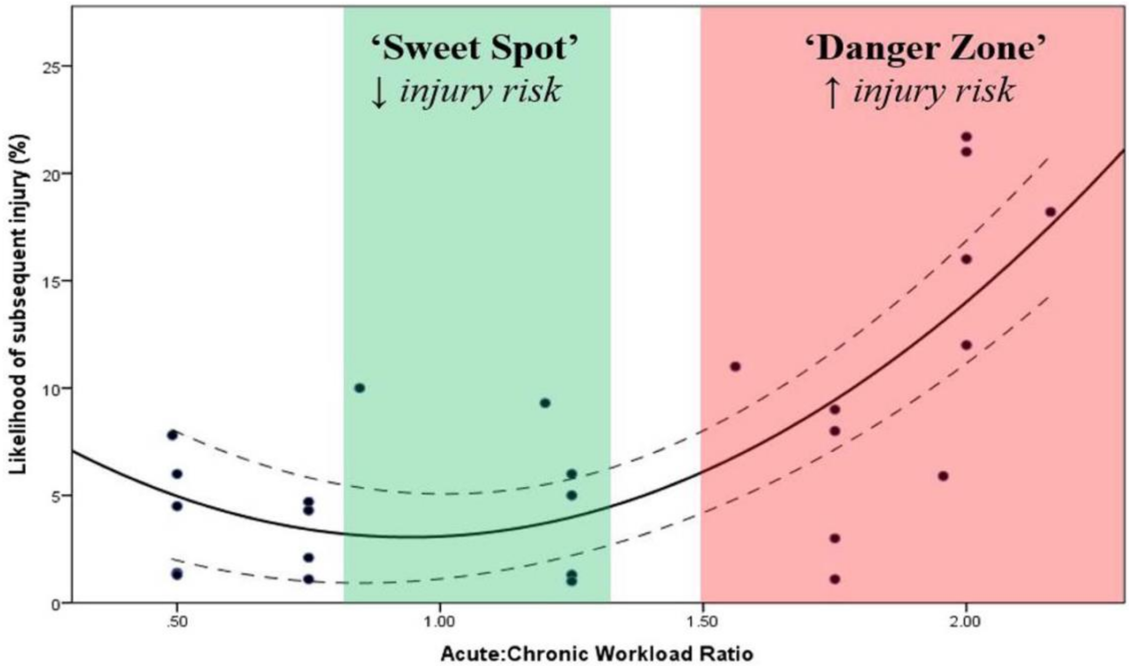

Figure 5: The training-injury prevention paradox: should athletes be training smarter and harder? T. J. Gabbett, 2016, British Journal of Sports Medicine, 50, p. 273. Copyright 2016 British Journal of Sports Medicine.

2.4.6 Exponentially weighted moving averages

There have been some concerns surrounding the use of rolling averages to calculate TL (Menaspà, 2017). Firstly, when calculating rolling averages all workload in a given time frame is considered equal. Secondly, using this method does not consider the decaying nature of fitness and fatigue effects over time. To solve these problems an alternative method, the “exponentially weighted moving averages” (EWMA), has been proposed. The EWMA-method emphasis the most recent workload by assigning a decreasing weighting for each older load value. The EWMA is potentially more sensitive to subtle changes in load and therefore to a larger degree influences where an athlete sits on the “ACWR spectrum” (Williams, West, Cross, & Stokes, 2017). Indeed, in a study by N. B. Murray, Gabbett, Townshend, and Blanch (2016) using fictional data they showed that the EWMA model offered greater sensitivity in identifying injury likelihood at higher ACWR ranges (1.50–1.99 and >2.0) during both the preseason and in-season periods (Murray et al., 2016). Furthermore, when TL is not following weekly patterns in team sports, the rolling weekly averages may disregard variations in TL within the week and as such are not ideal (Menaspà, 2017).

Despite the proposed advantage of the EWMA there is currently no evidence that this is a better method to calculate the ACWR (M. Drew, Blanch, Purdam, & Gabbett, 2016). Other authors have also argued against the superiority of using EWMA, suggesting that one model may not be the best "fit" for all sports (Sampson, Fullagar, & Murray, 2017).

2.4.7 Association between ACWR and injury in football

In football, several studies have investigated the ACWR-injury relationship (Table 2). Most studies include elite adult football players and to the authors knowledge, only two has been conducted on youth elite football players (Bowen et al., 2016; Watson et al., 2016). All of the studies are conducted on players that has been classified as elite. All of the studies are using a *time loss* definition. The sRPE is the most common TL-metric but many are using external TL-metrics such as GPS in addition. For the analysis of the TL-injury relationship, all studies are using additional calculations methods such as cumulative load over weeks and week-to-week changes (table 2).

In general, an association between the ACWR and injury is found in these studies. However, the results are not clear and there are variations in the associations depending on which TL-metric and calculated method that has been used (table 2).

Table 2: Overview of studies that have investigated the ACWR-injury relationship in football.

Study	Method/TL-metrics	Injury definition	Training load calculations	Results
Bowen et.al (2017) 2-season	N = 32 elite youth male football players Measures: GPS/accelerometer (TD, HSD, TL, ACC)	Time loss (contact vs non-contact injury), medical attention.	Cumulative 1-,2-,3-,4- weekly loads ACWR rolling averages (1:4)	The injury risk was greatest when very high number of accelerations were accumulated over 3 weeks (overall and non-contact injury) Increased risk of non-contact injury when high acute HSD combined with low chronic HSD, but not high chronic HSD. Contact injuries significant related to 1-weekly "spikes" in various workload measures. ACWR TD and ACC were very high.
Delecroix et.al (2018) 1-season	N = 130 elite male football players Measures: sRPE	Time loss (non-contact injury), medical attention.	Cumulative 1-,2-,3-,4- weekly loads. Week-to-wek load change. ACWR rolling avarges calculated for 1:2, 1:3, 1:4 time frames.	High cumulative 3 and 4-weeks TL were associated with increased injury risk. ACWR distant from 1, using 1:2, 1:3, 1:4 were significantly associated with non-contact injury incidence.
Fanchini et.al (2018) 3-season	N = 34 elite male football players Measures: sRPE	Time loss (non-contact injury), medical attention.	Cumulative 1-,2-,3-,4- weekly loads. Week-to-wek load change. ACWR rolling avarges calculated for 1:2, 1:3, 1:4 time frames.	Load markers based on sRPE as ACWR (1:2, 1:3, 1:4) was significantly associated with non-contact injury in elite football players.
Jaspers et.al (2017) 2-seasons	N = 35 elite male football players Measures: sRPE, GPS/accelerometer (TD, THSR, n = ACCeff and DECeff)	Time loss (overuse injuries), medical attention.	Cumulative 1-,2-,3-,4- weekly loads for TD, DECeff and sRPE. ACWR rolling averages (1:4) for all variables.	Higher cumulative 1-,2-,3 weekly loads for TD, and 2-3-4 for DECeff increased injury risk in the subsequent week. High ACWR and medium 1-w load for THSR increased injury risk in subsequent week. Medium ACWR for ACCeff, DECeff and sRPE lower injury risk in subsequent week.

Study	Method/TL-metrics	Injury definition	Training load calculations	Results
Lu et.al (2017) 1-season	N = 45 elite male football players Measures: sRPE, Exposure, GPS/accelerometer (TD,speed-zones, mean speed, body load)	Time loss (non-contact injury).	Cumulative 1-,2-,3-,4- weekly loads. Week-to-week load change. ACWR rolling averages calculated for 1:2, 1:3, 1:4 time periods	No specific profile existed before an injury other than sustained high exposure and sRPE workload-related loads in both absolute and relative terms. Such lack of distinct profile of either internal or external load was also reflected in the lack of week-to-week change and ACWR. Acute sustained high workloads relative to an individual player's norm existed prior to injury
Malone et.al (2017) 1-season	N = 48 elite male football players Measures: sRPE, Yo-Yo IR1	Time loss.	Cumulative 2-,3-,4- weekly loads Absolute change in load from the previous week. ACWR rolling averages (1:4)	Increased risk of injury when experiencing high one weekly cumulative training loads. Increasing risk when cumulative load was higher or large weekly changes in load were experienced. Higher intermittent-aerobic capacity offered protection against rapid increases in workloads and ACWR of 1.00–1.25 offered protective effects for players.
Malone et.al (2018) 1-season	N = 37 elite male football players Measures: sRPE, GPS (HSR, SR), 30–15 intermittent fitness test)	Time loss	Chronic training load (averaged 21-day load) Absolute change in load from the previous week Football based ACWR rolling averages (3-day acute load and 21-day chronic load period).	A U-shaped curve was found between high-speed and sprint based running load and injury risk. The data suggested that a 3:21 day ACWR for both high speed and sprint-based running was related to injury risk. Higher chronic TL allowed players to be exposed to increased volumes of running at reduced risk. Higher intermittent aerobic fitness allowed players to tolerate higher running volumes and changes in running volumes at reduced risk of injury.

Study	Method/TL-metrics	Injury definition	Training load calculations	Results
McCall et.al (2018) 1-season	N = 171 elite male football players Measures: sRPE	Time loss (non-contact injury)	Cumulative 1-,2-,3-,4- weekly loads. Week-to-week load change ACWR rolling averages, 1:2, 1:3, 1:4.	ACWR at 1:4 of 0.97-1.38 (RR 1.68) and > 1.38 (RR 2.13) increased risk compared to players with ACWR of 0.60-0.97. ACWR at 1:3 of > 1.42 compared to players with ACWR of 0.59 to 0.97 (RR 1.9) TL had poor predictive ability in isolation to identify individual players who would actually go on to incur a non-contact injury
Watson et.al (2017) 20-week season	N = 75 elite female youth football players Measures: sRPE	Time loss, self-reported.	Cumulative daily, ACWR rolling averages 1:4.	Higher acute TL was associated with increased injury risk, while higher chronic TL increased the risk of illness. Higher TL from the previous day exerted an independent effect on the risk of injury. The influence of chronic TL on injury was less clear. The ACWR was a significant predictor of injury.

TD = Total distance, DL = Distance x mean speed, SD = distance covered above 75% of individual player maximum speed, THSR = distance covered at high speed > 20 km/t,, HSD >20km/t, HSR >14.4, SR > 19.8, ACCeff = acceleration efforts > 1 m/s2, DECeff = deceleration efforts < -1m/s2

3. Method

3.1 Study design and experimental approach

We performed a prospective cohort study to assess the association between training load and injury incidence among male and female elite youth football players in the age group 15-19 year. Daily reporting of football training load and football related injuries were collected from the players using repeated questionnaires over 15 consecutive weeks (03.07.17-15.10.17). A simplified outline of the study is shown in figure 6.

The training load - and injury data in this study was collected in conjunction with a PhD-project examining TL as a risk factor for health problems. The method for the entire project is described, but present study is only concerned with the data on football related TL and injuries.

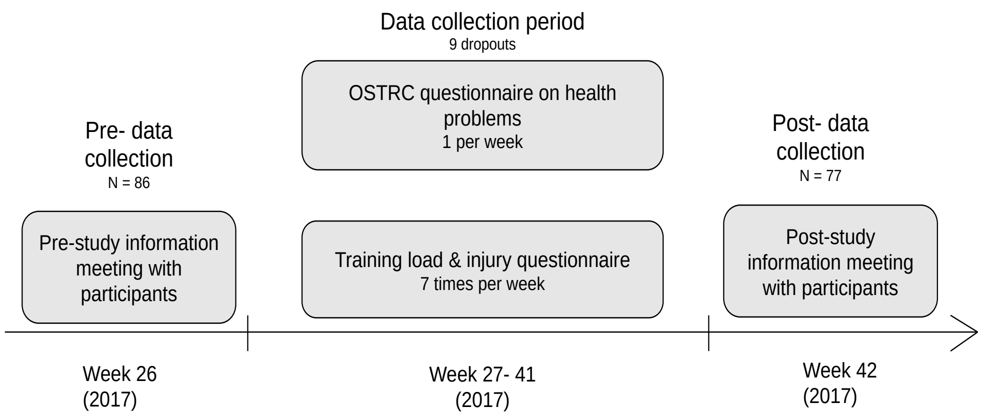

Figure 6: A simplified outline of the study.

3.2 Cohort and recruitment process

Twelve predetermined teams (coach or member of staff) from the elite youth division were contacted through email in the period of May-June 2017 and invited to participate in the study. Teams that already had implemented TL-monitoring system could not participate in the study. No power calculation was conducted for the estimation of sample size, however following recommendation from a statistician a practical estimation of approximately 100 participants was desirable.

A total of six teams agreed to participate in the study, five teams from the Oslo region and one from Sør-Trøndelag region. All participants were considered highly trained junior football players, competing at a junior elite level. To be included in the study the participants were required to be permanent members of their respective team and play in one of the following leagues: Nasjonal gutter 19, interkrets gutter 19, interkrets jenter 19. All participants had to understand Norwegian or English to participate in the study.

In the recruitment process, a member of the research group visited the included teams during a scheduled training where a standardized and detailed oral and written description about the project was given to the team coaches and players (Appendix I). All participants were verbally informed of the purpose and procedures of this study. All participants were provided written informed consent prior to participation (Appendix I), and informed that they were free to quit any time during the study period. Participants under the age of 16 had to provide written consent from their guardian to participate in the study. All written consents were handled by project manager. Participants that, for some reason, were absent from training on the recruitment day received the same information and possibility to participate in the study on a second team visit. A total of 86 participants (boys n= 47, mean age=17.5 ± SD and girls n= 39, mean age=17.5 ± SD) agreed to participate in the study.

The study has been conducted in accordance to the Helsinki declaration. The Regional Committees for Medical Research Ethics (Appendix II) and the Norwegian Social Science and Data Service (Appendix III) approved the study (NSD:54857/3/AMS, REK:2017/1015A, NIH ethics committee: 17-220817).

3.3 Methods of assessment

A self-reporting surveillance system was adopted. The method for data collection was by administration of questionnaires. A research smartphone application for longitudinal studies (Briteback Explore, https://briteback.com/en/solutions/research/) was used to administer the questionnaire to the participants. Each participant received a personal short message service (SMS) linking them to an internet-based questionnaire.

3.3.1 Training load recordings

In the present study, TL was defined as “the cumulative stress placed on an individual from multiple training sessions and games over a period of time” (Gabbett et al., 2014).

The TL monitoring metric in the daily questionnaire (figure 7) on training load and injury was the sRPE-method developed by Foster et al. (2001). The sRPE-method estimates training load by multiplying total session duration in minutes with the perceived intensity using a Norwegian version of the modified Borg category rating (CR-10) RPE (rating of perceived exertion) scale. The Borg CR-10 (figure 7) is a category scale ranging from 0 – 10, where 0 is rest and 10 is maximal effort (Foster et al., 2001). The training load (sRPE) is expressed as arbitrary units (AU) (Gabbett, 2010).

Rating	Description
0	Rest
1	Very, very Easy
2	Easy
3	Moderate
4	Somewhat Hard
5	Hard
6	.
7	Very Hard
8	.
9	.
10	Maximal

Figure 7: RPE-scale as modified by Foster et al. (2001).

3.3.2 Injury recordings

In the present study, an *all complaints* definition was adopted, and injury was defined as “any physical complaint resulting from competition or training, regardless of its consequence on sports participation or performance” (Fuller et al., 2006).

Weekly questionnaire on health problems

Health problems were documented each week using the Norwegian version of the self-reported OSTRC questionnaire on health problems (Clarsen et al., 2014). The SMS-questionnaire flow of the OSTRC is described in figure 8. The questionnaire consists of four key questions on the consequences of health problems on sports participation, training volume and sports performance, as well as the degree to which they have experienced symptoms. The method is a sensitive and valid tool to document acute injuries, overuse injuries and illnesses (Clarsen et al., 2014).

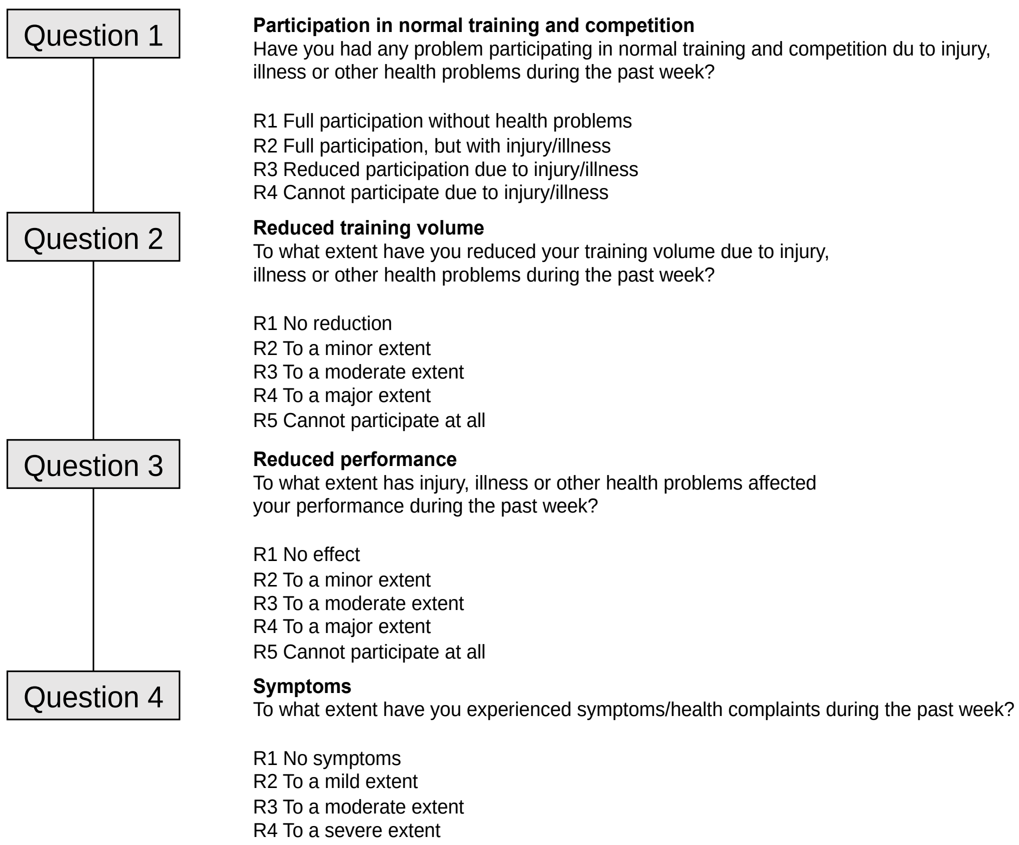

Figure 8: Flowchart of the weekly SMS OSTRC-questionnaire on health problems.

Daily questionnaire on training load and injury

The daily questionnaire contained a standardised set of questions on training load and health problems (figure 9). The structure of the questionnaire started by asking the participants if they had played any football that day. They were only to report football related activity (including school based- and individual training sessions), other training activities were not to be registered. If they did not report any football that day, they continued answering if they had any new health problem or worsening of an existing problem. If the participant reported a training session or match, the questionnaire continued by asking them how many training sessions (1-3) and further, how many minutes they played and at what intensity (RPE). They then continued answering if they had any new health problem or worsening of existing problem.

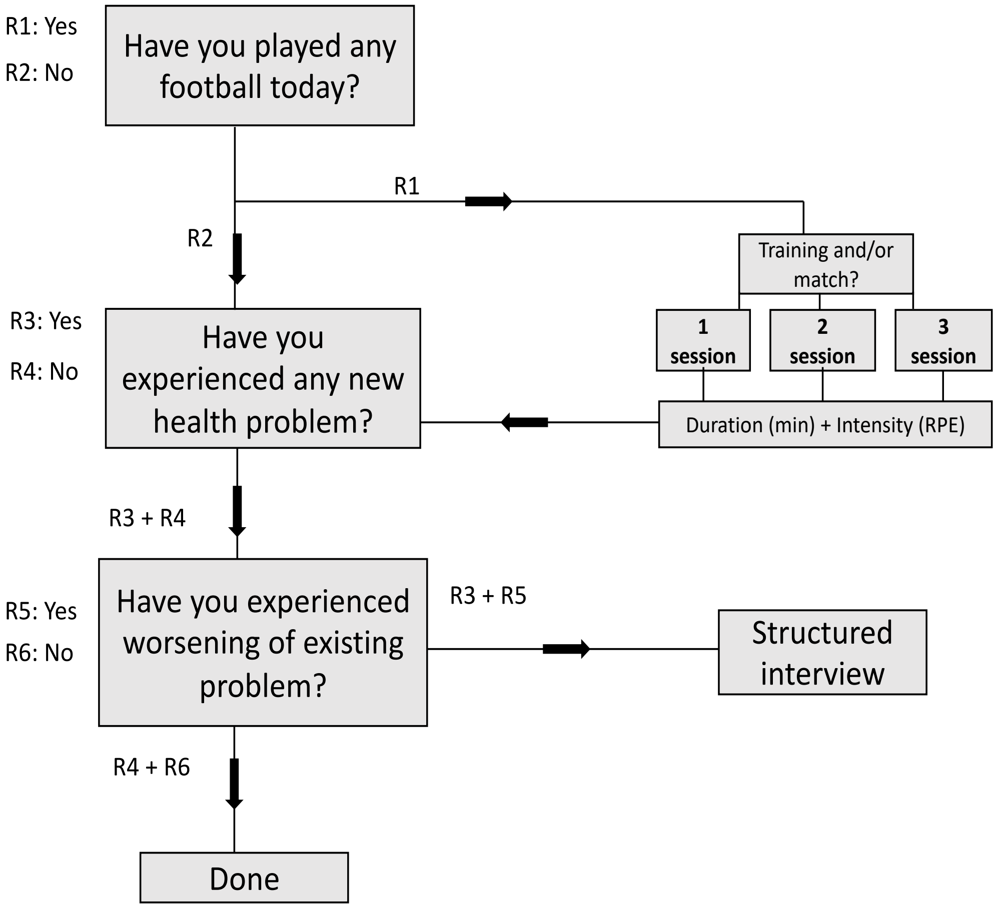

Figure 9: Flowchart of daily SMS-questionnaire on training load and health problem.

3.4 Experimental procedures

The standardised questionnaire on daily training load and health problems was distributed to all participants using the automatically SMS-system. The participants received a text message at 21:00 PM linking them to an internet-based questionnaire where they registered daily training load and health problems. If any participant did not respond, a group-SMS reminder was automatically sent the next morning at 09:00 AM. If the participant had not responded on the first, or second follow-up, they received a third reminder from one of the project researchers. Every Sunday at 21:00 PM the OSTRC-questionnaire on health problems was administered to the participants. Non-responders received reminders in the same order as described for the daily questionnaire.

If the participant reported a new health problem or worsening of an existing health problem in the daily report or the weekly questionnaire, one of the project coordinators contacted them for a structured phone interview regarding the reported issue (Attachment 3). The structured interview contained questions regarding injury location, type of injury (acute vs overuse) and mechanism of injury (contact vs non-contact). An acute injury was referring to an injury resulting from a specific, identifiable event, and an overuse injury to one caused by repeated micro trauma without a single, identifiable event responsible for the injury (Fuller et al., 2006). A contact injury was referring to an injury caused by contact with another player or with an object (e.g., ball, ground, or posts) (Fuller et al., 2006). The interview was attempted completed the same day as the injury was reported. If the participant did not answer her/his phone, a new attempt was made the day after.

3.5 Data processing and storage

All answers from the questionnaires were automatically stored on a secured server in the Briteback software (Briteback Explore,https://briteback.com/en/solutions/research/). A data handler extracted the daily registrations from the Briteback database and sorted the data in Microsoft Excel version 16. A daily report containing response rate and number of registered health problems was distributed to the other researches. To protect the participants personal identity, the daily report only contained the participants unique ID-number. Information regarding which participants should be contacted for the structured telephone interview was found in the daily report. Each researcher had access to a document containing the participants unique ID, personal identity and contact information. The participants personal data was de-identified, three-months after end of study.

3.6 Data analysis

All injury and TL-data was organised in Microsoft Excel version 16 and is presented as "raw data". Central tendency of the data was calculated as mean and standard deviation, when possible. Injuries were calculated as incidence and expressed as the frequency of injuries per 1000 hours of sports participation (Fuller et al., 2006). An injury that occurred in a week where the athlete reported a reduction in training dosage in the OSTRC- questionnaire was classified as a *time loss* injury.

Only new non-contact injuries were included in the data analysis of ACWR-injury relationship. The ACWR was calculated as 7 days recent TL divided by the last 28 days last TL using rolling averages (RA). Furthermore, analysis of the same time period was executed using the EWMA-method as described by Williams et al. (2017). Furthermore, TL-data was classified into the three discrete ranges, for both RA and EWMA, according to the sample z-scores (low ratio, medium ratio, high ratio) as well as for ratios similar as described by Blanch and Gabbett (2016) et al, 0-0.88 (low), 0.88-1.5 (medium) and >1.5 (high), from now on referred to as traditional ratios (Blanch & Gabbett, 2016).

3.7 Statistical analysis

For the ACWR analysis, TL -and injury data were transferred from Microsoft Excel version 16 to Stata version 12.0 software (StataCorp, College Station, TX, USA). To assess the association between ACWR and new non-contact injuries, a random effect logistic regression analysis was conducted using the command “xtlogit”. A significant level of 5% (p=0.05) was used in the ACWR analysis. The ACWR is presented as odds ratios (OR) and 95% confidence interval (CI).

4. **Results**

4.1 Response rate

A total of 86 players participated during the first study week. From week two to seven, nine participants (boys n=8 and girls n=1) dropped out of the study for various reasons. The remaining 77 participants continued throughout the study.

Of the 9030 potential observations, a total of 6250 observations were made and 74 new injuries were reported. The average response rate for the participants to the daily questionnaire throughout the 15-week study was 71%. The highest average response rate was 90% for the first week and the lowest rate was 63% the last week. Figure 10 shows the average weekly response rate during the course of the study.

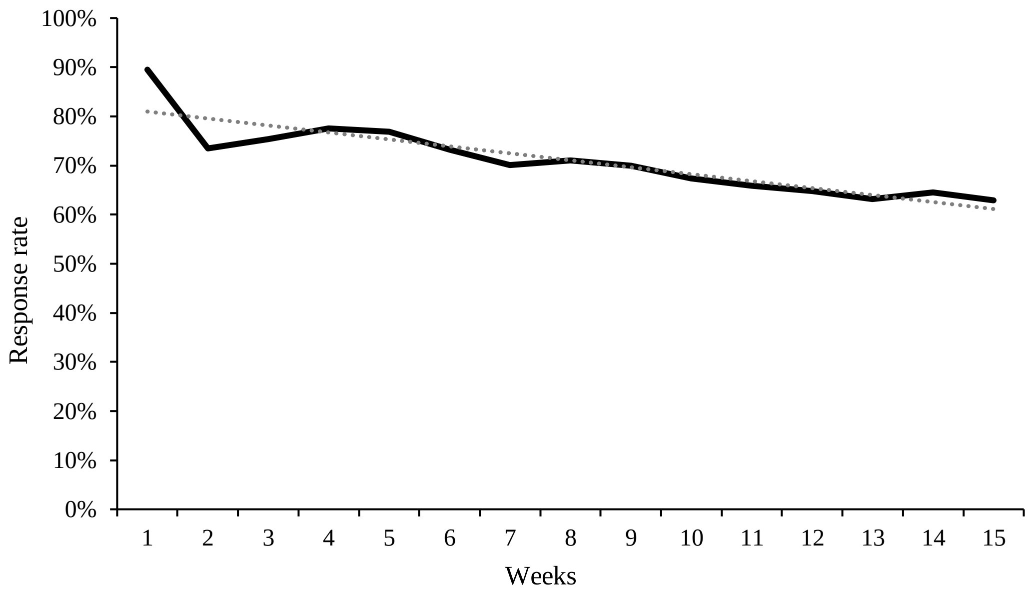

Figure 10: Weekly average response rate with trend line.

4.2 Injury data

4.2.1 Injury incidence

During the 15-week study, a total of 45 unique players (52% of all players) registered a new injury. This is equivalent to 0.9 injuries per player during the study period. Incidence rate using the different injury definitions are presented in table 3.

For all new injuries, 61% were classified as non-contact while 34% was classified as contact. Residual percentages could not be classified due to missing information on injury site. Furthermore, a total of 30% of new injuries were classified as time loss while 65% were non-time loss. For new non-contact injuries, 20% were time loss injuries while for new contact injuries 36% were time loss.

Table 3: Incidence rate per 1000 exposure hours.

Injury variable	Injuries, n	Exposure, h	Incidence Rate
New injury	74	4668	15.9
Time loss	22	4668	4.7
Non-time loss	48	4668	10.3
Non-categorised	4	4668	0.9
New non-contact	45	4668	9.6
Time loss	9	4668	1.9
New contact	25	4668	5.4
Time loss	9	4668	1.9

4.2.2 Injury location and mechanism

Lower extremity injuries accounted for 66% of all new injuries. A total of 61% of all injuries were acute and 36% were reported as overuse. The most frequent location was the knee (18%), ankle (19%) and groin/hip (11%). A total of 20% of all new injuries had non-identified location due to missing information. The ankle was the most frequently reported acute injury (29%) and also contact injury (40%). The knee was the most frequently reported overload injury (26%) and also non-contact injury (26%). Injury locations is presented in table 4.

Table 4: Injury locations, categorised by injury mechanism.

Injury location	Registered injuries, n	Acute injury, n	Overuse injury, n	Contact injury, n	Non-contact injury, n
Head/Neck	3	3	–	3	–
Neck/Cervical	–	–	–	–	–
Sternum/Upper back	–	–	–	–	–
Shoulder/Clavicle	–	–	–	–	–
Abdomen	–	–	–	–	–
Lower back/Pelvis	5	3	2	3	2
Overarm	–	–	–	–	–
Elbow	–	–	–	–	–
Wrist	–	–	–	–	–
Hand/Fingers	2	2	–	–	2
Hip/Groin	8	3	5	1	7
Thigh	7	5	2	1	5
Knee	13	6	7	1	11
Leg/Achilles	6	2	3	1	4
Ankle	14	13	1	10	4
Foot/Toe	1	–	1	–	1
Non-categorised	15	8	6	5	9
Total	74	45	27	25	45

4.3 Training load data

4.3.1 Training and match exposure

The total exposure of football training and match for all players during the entire study was 4668 hours. This equals an average (± SD) weekly football exposure of 245 ± 340 training minutes and 60 ± 168 match minutes per player and a total average weekly exposure of 305 minutes ± 340 per player (figure 11).

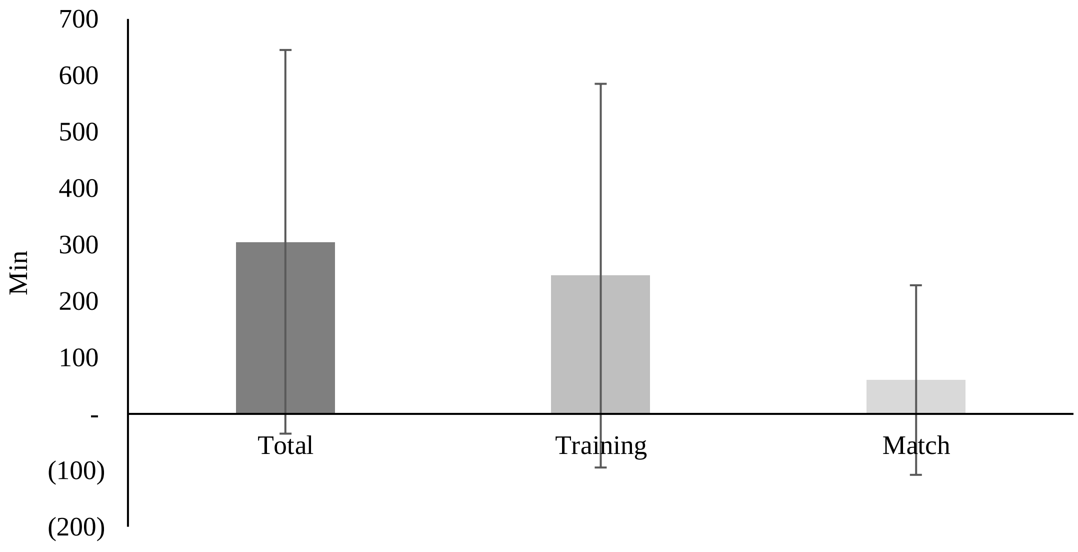

Figure 11: Weekly training, matches and total exposure minutes per player. Values are mean ± SD (lines).

4.3.2 Session-RPE

The mean (± SD) weekly training sRPE per player throughout the study was 1197 ± 555 AU. The mean (± SD) weekly match sRPE per player was 435 ± 108 AU. The lowest weekly mean (± SD) training sRPE was 717 ± 246 AU in the first week and 59 ± 77 AU for match in the second week. The peak weekly mean (± SD) sRPE for training was seen in week 5 1565 ± 487 AU and for match 638 ± 176 AU week 9.

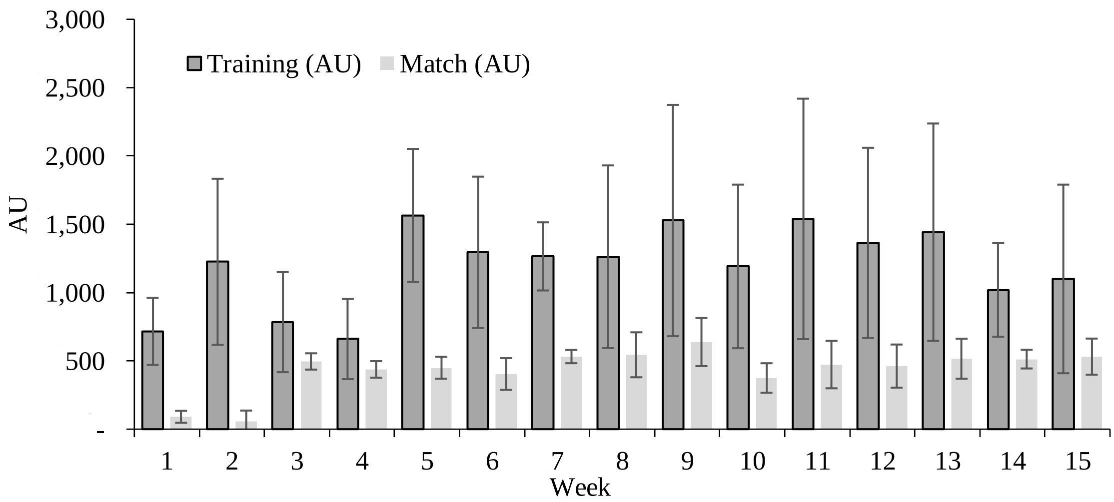

Figure 12: Weekly average sRPE for training and match.

4.3.3 The acute:chronic workload ratio

Of the 45 new non-contact injuries registered, 33 were included in the analysis due to inconsistency in TL-data from some of the participants. The ACWR was calculated as 7 recent days TL divided by the 28 last days TL using rolling averages (RA) and the EWMA-method. However, because of the inconsistency in the TL-data, 5-day acute and 20-day chronic TL was accepted as a minimum ratio. To be able to calculate the dataset as a 7:28 day ACWR, the mean TL from the 5:20 day ratio was used to complete the dataset.

The calculated ACWR-variables are presented as abbreviation in the text (table 5). TL-ratios are presented as low, medium and high category. A detailed description of the variables, including category range, OR (95% CI) for comparison between risk in different categories and p-value are presented in table 6.

Table 5: Abbreviations for the four different calculated ACWR-variables.

Calculation method (7:28 days)	**TL-variable categorisation**	**Abbreviation**
Rolling averages	z-scores	(RA z-scores)
Rolling averages	traditional	(RA traditional)
Exponential weighted moving averages	z-scores	(EWMA z-scores)
Exponential weighted moving averages	traditional	(EWMA traditional)

When ACWR was analysed as (RA z-scores), the high ratio category displayed a statistically significant risk of non-contact injury compared with the medium ratio category, but not compared with the low ratio category. The low ratio category did not have a different risk compared to medium ratio category.

When ACWR was analysed as (RA traditional), the high ratio category did not have a different risk of non-contact injury compared with the low and medium ratio category. The low ratio category did not have a different risk compared to medium ratio category.

When ACWR was analysed as (EWMA z-scores), the high ratio category had a statistically significant risk of non-contact injury compared with the medium ratio category. The high ratio category did not have a different risk compared to the low ratio category and the low ratio category did not have a different risk compared to medium ratio category.

When ACWR was analysed as (EWMA traditional), the high ratio category had a statistically significant risk of non-contact injury compared with the low ratio category, but not with the medium ratio category. The low ratio category did not have a different risk compared to medium ratio category.

In summary, analysis of the ACWR as (RA z-score) and (EWMA z-score) displayed a statistically significant higher risk of injury for the high ratio category compared with the medium ratio category. Furthermore, the analysis of the (EWMA traditional) variable displayed a statistically significant risk of non-contact injury high ratio category compared with the low ratio category.

Table 6: The analysis of the four different ACWR-variables with Tl-categories compared with reference category. The number of injury incidents and incidence is presented for each respective TL-category as well as OR with 95% CI for each category compared to the reference category.

Variables	**Category**	**Incidents, n**	**Incidence**	**Odds ratio (95% CI)**	**P-value**
RA z-scores	0-0.4 (reference)	3	32.0		
	0.4-1.81	22	7.8	1.0 (0.1-8.3)	0.98
	>1.81	8	21.5	5.7 (0.6-52.5)	0.12
	0.4-1.81 (reference)	22	7.8		
	0-0.4	3	32	1 (0.1-7.8)	1.98
	>1.81	8	21.5	5.5 (1.7-18.4)	0.01
RA traditional	0-0.88 (reference)	8	9.8		
	0.88-1.5	15	8.2	1.1 (0.3-4.5)	0.93
	>1.5	10	15.3	2.3 (0.5-10)	0.25
	0.88-1.5 (reference)	15	8.2		
	0-0.88	8	9.8	0.9 (0.2-4)	0.93
	>1.5	10	15.3	2.2 (0.6-7.8)	0.22
EWMA z-scores	0-0.32 (reference)	1	9.8		
	0.32-1.73	24	8.0	0.8 (0.1-6.3)	0.81
	>1.73	8	32.9	5.2 (0.6-45.7)	0.14
	0.32-1.73 (reference)	24	8.0		
	0-0.32	1	9.8	1.3 (0.2-10.6)	0.81
	>1.73	8	32.9	6.7 (2.2-21.1)	0.00
EWMA traditional	0-0.88 (reference)	8	20.8		
	0.88-1.5	15	13.2	2.2 (0.5-10.6)	0.33
	>1.5	10	17.6	6.5 (1.2-33.7)	0.03
	0.88-1.5 (reference)	15	13.9		
	0-0.88	8	20.4	0.5 (0.1-2.2)	0.33
	>1.5	10	27.6	3 (0.9-9.5)	0.07

5. Discussion

The aim of the present study was to (1) Investigate injury incidence in a cohort of youth elite football players and (2) Investigate the relationship between TL and injury incidence using the ACWR-method. The main finding of the study indicates that players with a large change in relative TL have an increased risk of sustaining injury compared to the players with medium and low change in TL. Furthermore, our results indicate a high injury incidence among youth elite football players. However, injury incidence varied according to how injury was defined.

5.1 Injury data

5.1.1 Injury incidence

In the present study, an injury rate of 15.9 per 1000 exposure hours was revealed using a true *physical complaints* definition. Of total injury incidence, 4.7 per 1000 exposure hours were categorised as *time loss* injuries and 10.3 per 1000 exposure hours were categorised as *non-time loss* injuries.

These results are in line with findings from previous studies. In a systematic review by Faude et al. (2013) on football injuries in children and adolescences they found an overall injury incidence in the range of 2-7 injuries per 1000 exposure hours for players in the age group 13-19 years. Furthermore, they reported increased incidence with age, reaching adults values by the age of 17-19 for both male and female players (Faude et al., 2013). In another systematic review by Pfirrmann et al. (2016) concerning injuries among male elite youth football players, it was reported an injury rate of 2-19.4 injuries per 1000 exposure hours (Pfirrmann et al., 2016).

The quite broad range of injury rate reported in the literature has been attributed to methodological inconsistencies between studies and especially the choice of injury definition (Clarsen & Bahr, 2014). Considering the injury rate found in present study, only including *time loss* injuries reduced incidence to approximately one third of that reported using an *all complaints* definition. Furthermore, when injury incidence was reported according to injury mechanism, injury rate also changed. If only considering non-contact injuries, injury rate was 9.6 per 1000 hours of exposure. This example highlights what previously has been reported, that choice of injury definition has a large impact on reported incidence.

A strength of this study was the use of a true *all complaints* definition which has shown to capture a larger number of injuries compared with *time loss* definition. This is especially important when studying overuse injuries that not necessarily lead to time loss and may be more relevant injury type when studying the TL-injury relationship. However, only a few studies have used a true *all complaints* definition making interstudy comparisons difficult.

5.1.2 Injury location and mechanism

In the present study, most injuries were related to the lower extremity (66%) where knee, ankle and hip/groin were the most frequent injury locations, respectively. These results are similar to what has previously been reported and in a systematic review by Faude et al. (2013) they found 60-90% of all injuries were located to the lower extremity where ankle, knee and thigh were the most frequent locations. However, it should be noted that injury location varied considerably between studies (Faude et al., 2013).

In this study, 34% was classified as contact injuries and 61% was classified as non-contact injuries. For comparison, Faude et al. (2013) found that 40-60% of all injuries were classified as contact injuries. Furthermore, in this study approximately 61% were classified as acute while 36% were classified as overuse injuries. This is similar to Faude et al. (2013) who reported that 60-90% of injuries were classified as acute while 10-40% were classified as overuse injuries (Faude et al., 2013).

5.2 Training load data

5.2.1 Training and match exposure

The weekly mean training and match exposure was 305 minutes ± 340 per player. This is much less than expected for elite youth football players that normally train for 90 min, 4-5 times per week in addition to match play.

5.2.2 Session-RPE

The weekly average TL in this study is less than previously reported in both elite youth and adult football players. In comparison, a study by Wrigley, Drust, Stratton, Scott, and Gregson (2012) monitored weekly in-season TL in a group of U18 elite youth football players. They found a weekly average TL of 3948 ± 222 AU. Furthermore, in elite male football players, Delecroix, McCall, Dawson, Berthoin, and Dupont (2018) reported a weekly average of 1914 ± 1080 AU during in-season while Malone, Owen, et al. (2017) reported an average weekly TL of 2441 ± 215 AU in-season and 2984 ± 615 AU off-season. It should be noted that the present study only included football related training as part of TL while the other studies mentioned included other training sessions such as strength training and rehabilitation that probably increased the total load per week. In the present study, weekly average was 1197 ± 555 AU for training and 435 ± 108 AU for match per participant. This training volume is less than expected for youth elite football players. The relatively low weekly average could be explained by several factors. Firstly, the first four weeks of our study had the lowest weekly total AU which may reflect the transition phase from in-season summer break to the second part of the season. In elite football, overall TL differs depending on which part of the season they are in (Impellizzeri, Rampinini, & Marcora, 2005). Secondly, the relatively low AU reported could also be a consequence of using a self-reported method to collect TL-data, where the participants are missing – or not accurately describing load. Despite having a quite high average response rate in this study, missing TL-data will have an impact on the average AU reported. Studies conducted on professional players will also probably have a higher response rate as TL-data is collected from personnel in the club.

5.2.3 The acute:chronic workload ratio

In football, an increasingly number of studies have investigated the relationship between the ACWR and risk of injury. Most of the research has been done on professional adult players and to the authors knowledge only two studies have investigated the elite youth population. Firstly, in a study by Bowen et al. (2016) on male elite youth players they found the ACWR to be related to both contact and non-contact injuries. However, TL-data were collected using GPS metrics and the dissimilar monitoring method used in this study limits the comparability of their results with the results from the present study (Bowen et al., 2016). Secondly, in a study by Watson et al. (2016) on female elite youth players they collected TL-data using the sRPE-method.

They concluded that the ACWR was a significant predictor of injury (OR 1.59, 95% CI 1.1-2.5) but did not specify which ACWR-category was at risk and therefore limits possibility for interstudy comparison (Watson et al., 2016).

More research exists on the elite adult football population where they have collected TL-data using sRPE or GPS/accelerometer, or a combination of both. In order to compare the results from the present study to findings from others, a list of studies using similar methodologies is presented in table 7.

Table 7: Studies investigated the TL-injury relationship using an ACWR 1:4 RA. TL-data categories and injury definitions are presented for each study. All results from the studies were stated as statistically significant results.

Study	**Category**	**Injury definition**	**Decreased risk (reference)**	**Increased risk (reference)**
Malone et al. (2017)	4 (Not available)	Time loss, contact & non-contact	>1.00-1.25 (<0.85)	>1.50 (<0.85)
McCall et al. (2018)	4 (Percentiles)	Time loss, non-contact		0.97-1.38 and >1.38 (0.6-0-97)
Fanchini et al. (2018)	4 (Percentiles)	Time loss, non-contact		0.78-1.02, 1.02-1.26 and >1.26 (<0.78)
Delecroix et al. (2018)	Z-scores	Time loss, non-contact	<0.85 (>0.85)	
Jaspers et al. (2017)	Tertiles	Time loss, overuse	0.85-1.12 and >1.12 (<0.85)	

According to Blanch and Gabbett (2016) there is a U-shaped relationship between the ACWR and risk of injury, where both high and low ratio would increase risk of injury while a medium ratio would be protective. In the present study, no statistically significant increased risk was found for the low ratio or the medium category in any of the calculated variables. Considering the studies presented in table 7, there seem to be an association between the ACWR and risk of injury in football. However, some of the results are conflicting. For example, Malone, Owen, et al. (2017) and Jaspers et al. (2017) both reported decreased risk for a medium ratio compared with low ratio while Delecroix et al. (2018) reported decreased risk for low ratio compared with medium ratio. Furthermore, McCall et al. (2018) and Fanchini et al. (2018a) reported increased risk for medium compared with low.

In the present study, a statistically significant increased risk of injury was only found in the high ratio categories. A high ACWR seems to elevate the risk of injury in most of the studies that are presented in table 7, except in the study by Jaspers et al. (2017) where they reported decreased risk for a high ACWR compared to low. However, in this study the high ratio category had a rather low threshold of only >1.12 which would probably be considered a medium ratio in most other studies.

It should be noted that not all studies have found a significant relationship between the ACWR and risk of injury in football. In a study by Lu, Howle, Waterson, Duncan, and Duffield (2017) they did not find high ACWR prior to injury. Furthermore, in a study by McCall et al. (2017) the ACWR did not conclusively define injured and non-injured players prior to - and during tournaments. There seem to be some conflicting results in the ACWR-literature with regards to which category ratio being is potentially associated with injury. The mmethodological variability between these studies may explain the inconsistency in results.

The choice of injury definition

Injury definition of choice will affect reported incidence and analysis of the TL-injury relationship. A recent editorial by Hulin (2017) brings attention to inconsistency in the use of injury definition in the TL-injury research. Furthermore, he argues that ignoring injury definition in the TL-injury analysis could influence the study findings and points to research showing conflicting evidence when using different injury definitions. A standardised method is important for interstudy comparison, however using different definitions should be considered depending on type of injury being investigating. Altering or selecting only one definition of injury when presenting data may result in findings that conflict with other research (Hulin, 2017). In football, most studies investigating the TL- injury relationship are only including non-contact, *time loss* injuries in their ACWR analysis. However, the choice of definition is not consistent through all studies and while some include contact injuries others only include overuse injuries (Jaspers et al., 2017; Malone, Owen, et al., 2017). In the present study, only new non-contact injuries were considered for the analysis of TL-injury relationship. The incidence of non-contact injuries was 9.6 injuries per 1000 hours exposure using a *physical complaints* definition. However, if only including the non-contact injuries leading to time loss in the analysis, incidence would be reduced to only 1.9 injures per 1000 hours exposure, equalling approximately 12% of total registered injuries or approximately 20% of non-contact injuries. Changing our injury definition would have affected the results from the TL-injury analysis.

The choice of training load measure

A range of different TL- measures for both internal and external load that can be used to collect TL-data and no single method exists that can measure the whole aspect of load (Soligard et al., 2016). When studying the TL-injury relationship, the choice of TL-measures will influence the result as different TL-metrics measures different aspects of load. An association between TL and injury may be evident when analysing TL-data based on sRPE but not necessarily GPS-data. Different monitoring methods may be used for different injuries. For example, using RPE is unlikely to be sensitive to subtle differences in sprinting intensity, which may be importance in terms of injury risk and prevention of hamstring injury in football (Buchheit, 2017). Instead, using GPS technology to measure high speed running may in this case be especially valuable for hamstring injury. Furthermore, most studies are only concerned with monitoring the physiological load, leaving out the psychological aspect of load. Even for a single TL-metric such as the sRPE, variation in its use can be found between studies as some choose to include not only football related activity, but also other activities such as strength training and rehabilitation, changing both type and magnitude of TL.

Calculation of the acute:chronic workload ratio

There is inconsistency in the statistical methods used to calculate the ACWR. Firstly, the categorisation of the ACWR TL-data differs between most of the studies (table 7). When the TL-data is categorised based on central tendency measures, the categories will fit the specific dataset in a better way than using for example fixed values (traditional). However, different measures of central tendencies are used to categorise TL-data which further complicates comparability between datasets. In the present study, TL categories were divided based on z-scores as well as the "traditional" values. The comparison of different category ratios could be considered a strength in this study as the association between TL and injury was shown to differ depending on category. For example, when categorising TL-variables using z-scores, the low ratio category had a very short range of only 0-0.32 (EWMA z-scores) and 0-0.4 (RA z-scores). The consequence of having these short ranges was that only three incidents went into the 0.4

category and only one incident went into the 0.32 category. In comparison, the low ratio category "traditional" ranging from 0-0.88 contained eight incidents. This example shows that choice of TL-categorisation can have a large impact on the results as categories only containing a few cases are extremely difficult to analyse.

Secondly, the ACWR can be calculated using a range of different time periods. The ACWR has normally been calculated as 1:4 weeks RA. This time period has been based on the "fitness-fatigue" model by Banister and Calvert (1980) which is supposed to have a physiological rational (Banister & Calvert, 1980; Blanch & Gabbett, 2016). The 1:4 time period also appears to align well with the periodisation strategies used in many team sports, although alternative time constants may be more appropriate for specific sports. It has been suggested that different ACWR time periods should be used to better fit the specificity of training and competitive patterns in specific sports. For example, in professional football, teams are playing 2-3 matches per week in-season and a specific football-based ACWR may instead comprise of a 3-day acute load period and a 21-day chronic load period (Malone, Owen, et al., 2017). The "optimal" ratio may also vary depending on what part of season they are in. Furthermore, in a team setting there are large individual differences in training and competition schedule, where some players don't compete as much as others. The usefulness of the ACWR in the elite football population has been questioned as defining a players locomotor profile is difficult which will likely limit the sensitivity of the method (Buchheit, 2017). In football, studies have found associations between ACWR and injury for 1:2, 1:3 and 1:4 time period (Delecroix et al., 2018; Fanchini et al., 2018a; McCall et al., 2018). In the present study, only a 1:4 time period was analysed as this period fitted well for the present cohort playing approximately 1 match per week. Furthermore, it is the most commonly used time period, making it easy to compare our results to previous studies.

Thirdly, ACWR can be calculated as rolling averages or EWMA. In a study by N. B. Murray et al. (2016) they EWMA-method displayed greater sensitivity in identifying injury likelihood at higher ACWR ranges (1.50–1.99 and >2.0). In football, all studies have calculated the ACWR rolling averages. In the present study, both methods were calculated. A statistically significant increased risk of injury (OR 6.6, 95% CI 1.2-33.7) was found for the high ratio category compared to the low ratio category when calculated as (EWMA traditional) as appose to (RA traditional) where no statistically significant were found (OR 2.3, 95% CI 0.5-10). These results can imply that the EWMA-method, indeed is a more sensitive method for the identification of injuries in the high ratio category.

Furthermore, a recent paper by Lolli et al. (2017) brought attention to a potential problem with the conventional way of calculating the ACWR. As acute load data constitutes a substantial part of the chronic load data they are "mathematically coupled". A "Mathematical coupling" occurs when a number is represented in both the numerator and denominator of a ratio and can lead to the occurrence of a false association also known as spurious correlation. A spurious correlation is one that exists between two variables irrespective of any true biological association between those variables. To prove their hypothesis, they generated fictional TL data to simulate a typical dataset and showed a moderate-to large, positive (but false) correlation between the calculated chronic and acute load data (r =0.52, 95% CI 0.47 to 0.56). Although the 4 weeks of data were uncorrelated with each other, this "false" correlation is explained by the fact that the acute data are part of the calculation of the chronic phase data leading to mathematical coupling. This "false" correlation will therefore be present irrespective of any true physiological association between acute and chronic load variables, leading to biased inferences (Lolli et al., 2017). If the variables are not "truly" related to each other, the process of normalising acute to chronic load may be unnecessary and the acute load itself could be a useful predictor of injury in absolute terms (Lolli et al., 2018).

5.3 Limitations of this study

5.3.1 Study design

A limitation of the present study was the relatively short study period of 15 weeks, where the first few weeks constituted the transition from summer break to second part of the season. Fuller et al. recommended a study period of at least one season (including pre-season) and most previous studies in football have collected data throughout one or two seasons (table 1). A short study period may not reflect true injury incidence as this may vary through the year.

5.3.2 Injury definition and recordings

The *time loss* injuries found in this study were based on information from the OSTRC-questionnaire on health problems. This indirect method is probably less accurate than classification of *time loss* by medical personnel.

In the present study, injuries were classified according to an *all complaints* definition which captures "all symptoms" related to football related training. It is possible that some of the cases recorded may in fact be "normal" pain related to athletic participation rather than injury, for example, delayed-onset muscle soreness (Clarsen et al., 2012). Furthermore, using a self-reporting surveillance system is strongly dependent on honest and correct information from the participants. Indeed, an anonymous post-study questionnaire was conducted, where some of the participants admitted to omitting information.

A retrospective telephone interview was used to collect additional information regarding the reported injuries. However, we could not reach all of the participants and therefore approximately 20% of injury locations were not identified. Further, this recording method is subjected to interviewer and recall bias.

In the present study, injuries were reported as incidence. However, no distinction between match and training incidence were made, which has been recommended in the consensus agreement from Fuller et al. (2006). Furthermore, injury severity was not reported and focusing on incidence alone may give an incomplete and erroneous picture of risk. It has been recommended to combine incidence and severity and express this as "injury burden" (Roald Bahr, Clarsen, & Ekstrand, 2018).

5.3.3 Training load definition and recordings

In the present study, only internal load was measured. External load was not recorded which has been linked to injury in several studies (Soligard et al., 2016). When collecting TL-data, a combination of internal and external load measures as well as subjective and objective markers is preferred (Burgess, 2017).

5.3.4 Statistical method

In the present study, the ACWR was only analysed using a 1:4 week time period. Calculating additional ACWR time periods such as 1:2 and 1:3 may add valuable information on TL as a risk factor. Sample size calculation was not conducted at the study design stage and therefore it was unsure if the number of participants was adequate from a statistical point of view. Only 33 non-contact injuries were included in the ACWR analysis, leaving only a few injury incidents in each TL-category. Some of the low ratio categories contained only 1-3 incidents making it pointless to interpret results from statistical point of view. Furthermore, the statistical uncertainty in the results is reflected in very large confidence intervals for the OR-data. A larger sample size and especially longer study period would have been preferable for increasing the statistical certainty of the results.

5.4 Practical applications

Findings in the present study shows that injury rate is high among youth elite football players. Elite youth football clubs should implement risk management strategies to reduce the incidence of injuries in youth elite football. Lower extremity injuries such as ankle, knee, thigh and groin are the most common ones and should therefore be emphasised.

Furthermore, the present findings indicate that high ACWR increases the risk of injury. From a practical point, coaches and players should avoid increasing TL by more than 50% of what has been performed during the four last weeks. This study was performed in the environment of the teams and for practitioners such as coaches and trainers, monitoring TL using the sRPE and calculating the ACWR can be used as one strategy to reduce risk of injury as well as tool in the planning of sessions and training periods.

The ACWR is an increasingly popular and common tool to model the relationship between TL and injury in many sports. However, practitioners applying the ACWR in practice should not think of it as injury prediction tool. Training load should not be seen as an isolated risk factor but must be placed within the context of other risk factors which applies to the individual, team and sports.

5.4.1 Directions for future studies

Current research in the field of TL-injury relationship using ACWR has focused almost exclusively on the male elite population. However, most players are not elite, and many are females, which questions the extrapolation of current ACWR-data to other populations such as youth elite. More studies are needed for lower-level players at different age groups and both sexes.

It is well known that choice of definition will influence the reported injury data. For studies investigating the TL-injury relationship using the ACWR, careful considerations should be made on the choice of definition as it can greatly impact the results. Future studies should consider analysing the ACWR using different definitions. Furthermore, considerations should be made to what type of injury being investigated.

Another important factor for the outcome of TL-injury studies is the definition of load. The term “load” was defined as a broad term including both sport and non-sport stressors in the recent consensus statement. However, most studies only concerned with the physical part of load, ignoring other aspects such as psychosocial factors. For a true understanding of load as a risk factor, future studies should consider measuring additional aspects of load.

Injury aetiology is multifactorial and complex, but most studies investigating risk factors in sports medicine are concerned with single risk factors. Future studies should attempt to investigate the interaction between a web of risk factors. This would probably require longitudinal monitoring of multiple risk factors and the need to integrate computer science such as machine learning to understand the complex networks and patterns of risk factors that apply for the individual person and sport.

6. Conclusion

A high injury rate was found among elite youth football players. Using an *all complaints* definition resulted in approximately three times higher incidence compared with *time loss* criteria. Furthermore, findings in the present study indicate that players are at a higher risk of non-contact injury when experiencing high ACWR. No statistically significant risk was found for either medium- or low ACWR.

Considering the results from the present study, TL-monitoring should be implemented as part of injury reduction strategies in youth elite football. Coaches and players should avoid large spikes in TL over 50% of what has previously been done.

There is a lack of standardisation in the TL-injury relationship literature. Future studies in the field of TL-injury relationship are faced with many methodological challenges. The reported results from the ACWR-analysis is highly influenced by the choice of definition and the choice of TL-metric.

References

Arnason, A., Sigurdsson, S. B., Gudmundsson, A., Holme, I., Engebretsen, L., & Bahr, R. (2004). Risk factors for injuries in football. *The American journal of sports medicine, 32*(1_suppl), 5-16.

Bahr, R. (2009). No injuries, but plenty of pain? On the methodology for recording overuse symptoms in sports. *British Journal of Sports Medicine, 43*(13), 966-972.

Bahr, R. (2014). Demise of the fittest: are we destroying our biggest talents? In: BMJ Publishing Group Ltd and British Association of Sport and Exercise Medicine.

Bahr, R., Clarsen, B., & Ekstrand, J. (2018). Why we should focus on the burden of injuries and illnesses, not just their incidence. In: BMJ Publishing Group Ltd and British Association of Sport and Exercise Medicine.

Bahr, R., & Holme, I. (2003). Risk factors for sports injuries—a methodological approach. *British Journal of Sports Medicine, 37*(5), 384-392.

Bahr, R., & Krosshaug, T. (2005). Understanding injury mechanisms: a key component of preventing injuries in sport. *British Journal of Sports Medicine, 39*(6), 324-329.

Banister, E., & Calvert, T. (1980). Planning for future performance: implications for long term training. *Canadian journal of applied sport sciences. Journal canadien des sciences appliquees au sport, 5*(3), 170-176.

Barnes, C., Archer, D., Hogg, B., Bush, M., & Bradley, P. (2014). The evolution of physical and technical performance parameters in the English Premier League. *Int J Sports Med, 35*(13), 1095-1100.

Bergeron, M. F., Mountjoy, M., Armstrong, N., Chia, M., Côté, J., Emery, C. A., . . . Léglise, M. (2015). International Olympic Committee consensus statement on youth athletic development. *Br J Sports Med, 49*(13), 843-851.

Bianco, A., Spedicato, M., Petrucci, M., Messina, G., Thomas, E., Sahin, F. N., . . . Palma, A. (2016). A prospective analysis of the injury incidence of young male professional football players on artificial turf. *Asian journal of sports medicine, 7*(1).

Bittencourt, N., Meeuwisse, W., Mendonça, L., Nettel-Aguirre, A., Ocarino, J., & Fonseca, S. (2016). Complex systems approach for sports injuries: moving from risk factor identification to injury pattern recognition—narrative review and new concept. *Br J Sports Med*, bjsports-2015-095850.

Blanch, P., & Gabbett, T. J. (2015). Has the athlete trained enough to return to play safely? The acute: chronic workload ratio permits clinicians to quantify a player's risk of subsequent injury. *Br J Sports Med*, bjsports-2015-095445.

Blanch, P., & Gabbett, T. J. (2016). Has the athlete trained enough to return to play safely? The acute: chronic workload ratio permits clinicians to quantify a player's risk of subsequent injury. *Br J Sports Med, 50*(8), 471-475.

Borg, G. (1982). Ratings of perceived exertion and heart rates during short-term cycle exercise and their use in a new cycling strength test. *International journal of sports medicine, 3*(03), 153-158.

Borresen, J., & Lambert, M. I. (2009). The quantification of training load, the training response and the effect on performance. *Sports medicine, 39*(9), 779-795.

Bourdon, P. C., Cardinale, M., Murray, A., Gastin, P., Kellmann, M., Varley, M. C., . . . Gregson, W. (2017). Monitoring athlete training loads: consensus statement. *International Journal of Sports Physiology and Performance, 12*(Suppl 2), S2-161-S162-170.

Bowen, L., Gross, A. S., Gimpel, M., & Li, F.-X. (2016). Accumulated workloads and the acute: chronic workload ratio relate to injury risk in elite youth football players. *Br J Sports Med*, bjsports-2015-095820.

Brink, M. S., Frencken, W. G., Jordet, G., & Lemmink, K. A. (2014). Coaches' and players' perceptions of training dose: not a perfect match. *International Journal of Sports Physiology and Performance, 9*(3), 497-502.

Brink, M. S., Kersten, A. W., & Frencken, W. G. (2017). Understanding the mismatch between coaches' and players' perceptions of exertion. *International Journal of Sports Physiology and Performance, 12*(4), 562-568.

Brink, M. S., Nederhof, E., Visscher, C., Schmikli, S. L., & Lemmink, K. A. (2010). Monitoring load, recovery, and performance in young elite soccer players. *The Journal of Strength & Conditioning Research, 24*(3), 597-603.

Brink, M. S., Visscher, C., Arends, S., Zwerver, J., Post, W. J., & Lemmink, K. A. (2010). Monitoring stress and recovery: new insights for the prevention of injuries and illnesses in elite youth soccer players. *British Journal of Sports Medicine, 44*(11), 809-815.

Brito, J., Malina, R. M., Seabra, A., Massada, J. L., Soares, J. M., Krustrup, P., & Rebelo, A. (2012). Injuries in Portuguese youth soccer players during training and match play. *Journal of athletic training, 47*(2), 191-197.

Buchheit, M. (2017). Applying the acute: chronic workload ratio in elite football: worth the effort? In: BMJ Publishing Group Ltd and British Association of Sport and Exercise Medicine.

Burgess, D. J. (2017). The research doesn't always apply: practical solutions to evidence-based training-load monitoring in elite team sports. *International Journal of Sports Physiology and Performance, 12*(Suppl 2), S2-136-S132-141.

Chambers, R., Gabbett, T. J., Cole, M. H., & Beard, A. (2015). The use of wearable microsensors to quantify sport-specific movements. *Sports medicine, 45*(7), 1065-1081.

Clarsen, B., & Bahr, R. (2014). Matching the choice of injury/illness definition to study setting, purpose and design: one size does not fit all! *Br J Sports Med, 48*(7), 510-512.

Clarsen, B., Myklebust, G., & Bahr, R. (2012). Development and validation of a new method for the registration of overuse injuries in sports injury epidemiology. *Br J Sports Med*, bjsports-2012-091524.

Clarsen, B., Rønsen, O., Myklebust, G., Flørenes, T. W., & Bahr, R. (2014). The Oslo Sports Trauma Research Center questionnaire on health problems: a new approach to prospective monitoring of illness and injury in elite athletes. *Br J Sports Med, 48*(9), 754-760.

Clausen, M. B., Zebis, M. K., Møller, M., Krustrup, P., Hölmich, P., Wedderkopp, N., . . . Thorborg, K. (2014). High injury incidence in adolescent female soccer. *The American journal of sports medicine, 42*(10), 2487-2494.

Day, M. L., McGuigan, M. R., Brice, G., & Foster, C. (2004). Monitoring exercise intensity during resistance training using the session RPE scale. *The Journal of Strength & Conditioning Research, 18*(2), 353-358.

Delecroix, B., McCall, A., Dawson, B., Berthoin, S., & Dupont, G. (2018). Workload and non-contact injury incidence in elite football players competing in European leagues. *European journal of sport science*, 1-8.

DiFiori, J. P., Benjamin, H. J., Brenner, J. S., Gregory, A., Jayanthi, N., Landry, G. L., & Luke, A. (2014). Overuse injuries and burnout in youth sports: a position statement from the American Medical Society for Sports Medicine. *Br J Sports Med, 48*(4), 287-288.

Drew, M., Blanch, P., Purdam, C., & Gabbett, T. (2016). Yes, rolling averages are a good way to assess training load for injury prevention. Is there a better way? Probably, but we have not seen the evidence. *Br J Sports Med*, bjsports-2016-096609.

Drew, M. K., & Finch, C. F. (2016). The relationship between training load and injury, illness and soreness: a systematic and literature review. *Sports medicine, 46*(6), 861-883.

Ekstrand, J., Hägglund, M., & Waldén, M. (2011). Injury incidence and injury patterns in professional football: the UEFA injury study. *British Journal of Sports Medicine, 45*(7), 553-558.

Elias, S. R. (2001). 10-year trend in USA Cup soccer injuries: 1988-1997. *Medicine and science in sports and exercise, 33*(3), 359-367.

Fanchini, M., Rampinini, E., Riggio, M., Coutts, A. J., Pecci, C., & McCall, A. (2018a). Despite association, the acute: chronic work load ratio does not predict non-contact injury in elite footballers. *Science and Medicine in Football*, 1-7.

Fanchini, M., Rampinini, E., Riggio, M., Coutts, A. J., Pecci, C., & McCall, A. (2018b). Despite association, the acute: chronic work load ratio does not predict non-contact injury in elite footballers. *Science and Medicine in Football, 2*(2), 108-114.

Faude, O., Rößler, R., & Junge, A. (2013). Football injuries in children and adolescent players: are there clues for prevention? *Sports medicine, 43*(9), 819-837.

FIFA, C. (2007). FIFA Big Count 2006: 270 million people active in football. *FIFA Communications Division, Information Services, 31*, 2007.

Foster, C., Florhaug, J. A., Franklin, J., Gottschall, L., Hrovatin, L. A., Parker, S., . . . Dodge, C. (2001). A new approach to monitoring exercise training. *The Journal of Strength & Conditioning Research, 15*(1), 109-115.

Fuller, C. W., Ekstrand, J., Junge, A., Andersen, T. E., Bahr, R., Dvorak, J., . . . Meeuwisse, W. H. (2006). Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Scandinavian journal of medicine & science in sports, 16*(2), 83-92.

Gabbett, T. J. (2010). The development and application of an injury prediction model for noncontact, soft-tissue injuries in elite collision sport athletes. *The Journal of Strength & Conditioning Research, 24*(10), 2593-2603.

Gabbett, T. J. (2016). The training-injury prevention paradox: should athletes be training smarter and harder? *Br J Sports Med*, bjsports-2015-095788.

Gabbett, T. J., Nassis, G. P., Oetter, E., Pretorius, J., Johnston, N., Medina, D., . . . Beard, A. (2017). The athlete monitoring cycle: a practical guide to interpreting and applying training monitoring data. In: BMJ Publishing Group Ltd and British Association of Sport and Exercise Medicine.

Gabbett, T. J., & Whiteley, R. (2017). Two Training-Load Paradoxes: Can We Work Harder and Smarter, Can Physical Preparation and Medical Be Teammates? *International Journal of Sports Physiology and Performance, 12*(Suppl 2), S2-50-S52-54.

Gabbett, T. J., Whyte, D. G., Hartwig, T. B., Wescombe, H., & Naughton, G. A. (2014). The relationship between workloads, physical performance, injury and illness in adolescent male football players. *Sports medicine, 44*(7), 989-1003.

Harøy, J., Clarsen, B., Thorborg, K., Hölmich, P., Bahr, R., & Andersen, T. E. (2017). Groin problems in male soccer players are more common than previously reported. *The American journal of sports medicine, 45*(6), 1304-1308.

Haugaasen, M., & Jordet, G. (2012). Developing football expertise: a football-specific research review. *International Review of Sport and Exercise Psychology, 5*(2), 177-201.

Haugaasen, M., Toering, T., & Jordet, G. (2014). From childhood to senior professional football: elite youth players' engagement in non-football activities. *Journal of sports sciences, 32*(20), 1940-1949.

Hawley, J. A., Hargreaves, M., Joyner, M. J., & Zierath, J. R. (2014). Integrative biology of exercise. *Cell, 159*(4), 738-749.

Hawley, J. A., Lundby, C., Cotter, J. D., & Burke, L. M. (2018). Maximizing Cellular Adaptation to Endurance Exercise in Skeletal Muscle. *Cell metabolism, 27*(5), 962-976.

Hulin, B. T. (2017). The never-ending search for the perfect acute: chronic workload ratio: what role injury definition? In: BMJ Publishing Group Ltd and British Association of Sport and Exercise Medicine.

Hulin, B. T., Gabbett, T. J., Blanch, P., Chapman, P., Bailey, D., & Orchard, J. W. (2013). Spikes in acute workload are associated with increased injury risk in elite cricket fast bowlers. *Br J Sports Med*, bjsports-2013-092524.

Hulin, B. T., Gabbett, T. J., Lawson, D. W., Caputi, P., & Sampson, J. A. (2016). The acute: chronic workload ratio predicts injury: high chronic workload may decrease injury risk in elite rugby league players. *Br J Sports Med, 50*(4), 231-236.

Hulme, A., & Finch, C. F. (2015). From monocausality to systems thinking: a complementary and alternative conceptual approach for better understanding the development and prevention of sports injury. *Injury epidemiology, 2*(1), 31.

Hägglund, M., Waldén, M., & Ekstrand, J. (2013). Risk factors for lower extremity muscle injury in professional soccer: the UEFA Injury Study. *The American journal of sports medicine, 41*(2), 327-335.

Impellizzeri, F. M., Rampinini, E., Coutts, A. J., Sassi, A., & Marcora, S. M. (2004). Use of RPE-based training load in soccer. *Medicine & Science in sports & exercise, 36*(6), 1042-1047.

Impellizzeri, F. M., Rampinini, E., & Marcora, S. M. (2005). Physiological assessment of aerobic training in soccer. *Journal of sports sciences, 23*(6), 583-592.

Ivarsson, A., Johnson, U., & Podlog, L. (2013). Psychological predictors of injury occurrence: a prospective investigation of professional Swedish soccer players. *Journal of sport rehabilitation, 22*(1), 19-26.

Jaspers, A., Kuyvenhoven, J. P., Staes, F., Frencken, W. G., Helsen, W. F., & Brink, M. S. (2017). Examination of the external and internal load indicators' association with overuse injuries in professional soccer players. *Journal of science and medicine in sport*.

Kiely, J. (2018). Periodization theory: confronting an inconvenient truth. *Sports medicine, 48*(4), 753-764.

Kolstrup, L. A., Koopmann, K. U., Nygaard, U. H., Nygaard, R. H., & Agger, P. (2016). Injuries during football tournaments in 45,000 children and adolescents. *European journal of sport science, 16*(8), 1167-1175.

Kroelinger, C. D., Rankin, K. M., Chambers, D. A., Roux, A. V. D., Hughes, K., & Grigorescu, V. (2014). Using the principles of complex systems thinking and implementation science to enhance maternal and child health program planning and delivery. *Maternal and child health journal, 18*(7), 1560-1564.

Le Gall, F., Carling, C., & Reilly, T. (2008). Injuries in young elite female soccer players: an 8-season prospective study. *The American journal of sports medicine, 36*(2), 276-284.

Lolli, L., Batterham, A. M., Hawkins, R., Kelly, D. M., Strudwick, A. J., Thorpe, R., . . . Atkinson, G. (2017). Mathematical coupling causes spurious correlation within the conventional acute-to-chronic workload ratio calculations. In: BMJ Publishing Group Ltd and British Association of Sport and Exercise Medicine.

Lolli, L., Batterham, A. M., Hawkins, R., Kelly, D. M., Strudwick, A. J., Thorpe, R. T., . . . Atkinson, G. (2018). The acute-to-chronic workload ratio: an inaccurate scaling index for an unnecessary normalisation process? In: BMJ Publishing Group Ltd and British Association of Sport and Exercise Medicine.

Lu, D., Howle, K., Waterson, A., Duncan, C., & Duffield, R. (2017). Workload profiles prior to injury in professional soccer players. *Science and Medicine in Football, 1*(3), 237-243.

Lupo, C., Tessitore, A., Gasperi, L., & Gomez, M. (2017). Session-RPE for quantifying the load of different youth basketball training sessions. *Biology of sport, 34*(1), 11.

Malone, S., Owen, A., Mendes, B., Hughes, B., Collins, K., & Gabbett, T. J. (2018). High-speed running and sprinting as an injury risk factor in soccer: Can well-developed physical qualities reduce the risk? *Journal of science and medicine in sport, 21*(3), 257-262.

Malone, S., Owen, A., Newton, M., Mendes, B., Collins, K. D., & Gabbett, T. J. (2017). The acute: chonic workload ratio in relation to injury risk in professional soccer. *Journal of science and medicine in sport, 20*(6), 561-565.

Malone, S., Roe, M., Doran, D. A., Gabbett, T. J., & Collins, K. D. (2017). Protection against spikes in workload with aerobic fitness and playing experience: the role of the acute: chronic workload ratio on injury risk in elite Gaelic football. *International Journal of Sports Physiology and Performance, 12*(3), 393-401.

McCall, A., Dupont, G., & Ekstrand, J. (2018). Internal workload and non-contact injury: a one-season study of five teams from the UEFA Elite Club Injury Study. *Br J Sports Med*, bjsports-2017-098473.

McCall, A., Jones, M., Gelis, L., Duncan, C., Ehrmann, F., Dupont, G., & Duffield, R. (2017). Monitoring loads and non-contact injury during the transition from club to National team prior to an international football tournament: A case study of the 2014 FIFA World Cup and 2015 Asia Cup. *Journal of science and medicine in sport*.

McCunn, R., Sampson, J. A., Whalan, M., & Meyer, T. (2017). Data collection procedures for football injuries in lower leagues: Is there a need for an updated consensus statement? *Science and Medicine in Football, 1*(1), 86-88.

Meeuwisse, W. H. (1994). Assessing Causation in Sport Injury: A Multifactorial Model. In: LWW.

Meeuwisse, W. H., Tyreman, H., Hagel, B., & Emery, C. (2007). A dynamic model of etiology in sport injury: the recursive nature of risk and causation. *Clinical Journal of Sport Medicine, 17*(3), 215-219.

Menaspà, P. (2017). Are rolling averages a good way to assess training load for injury prevention? *Br J Sports Med, 51*(7), 618-619.

Milanović, Z., Pantelić, S., Čović, N., Sporiš, G., Mohr, M., & Krustrup, P. (2018). Broad-spectrum physical fitness benefits of recreational football: a systematic review and meta-analysis. *Br J Sports Med*, bjsports-2017-097885.

Moller, M., Wedderkopp, N., Myklebust, G., Lind, M., Sorensen, H., Hebert, J., . . . Attermann, J. (2018). Validity of the SMS, Phone, and medical staff Examination sports injury surveillance system for time-loss and medical attention injuries in sports. *Scandinavian journal of medicine & science in sports, 28*(1), 252-259.

Murray, A. (2017). Managing the training load in adolescent athletes. *International Journal of Sports Physiology and Performance, 12*(Suppl 2), S2-42-S42-49.

Murray, N., Gabbett, T. J., Townshend, A., Hulin, B. T., & McLellan, C. (2017). Individual and combined effects of acute and chronic running loads on injury risk in elite Australian footballers. *Scandinavian journal of medicine & science in sports, 27*(9), 990-998.

Murray, N. B., Gabbett, T. J., Townshend, A. D., & Blanch, P. (2016). Calculating acute: chronic workload ratios using exponentially weighted moving averages provides a more sensitive indicator of injury likelihood than rolling averages. *Br J Sports Med*, bjsports-2016-097152.

Nielsen, A. B., & Yde, J. (1989). Epidemiology and traumatology of injuries in soccer. *The American journal of sports medicine, 17*(6), 803-807.

Nilsson, T., Östenberg, A. H., & Alricsson, M. (2016). Injury profile among elite male youth soccer players in a Swedish first league. *Journal of exercise rehabilitation, 12*(2), 83.

Nilstad, A., Andersen, T. E., Bahr, R., Holme, I., & Steffen, K. (2014). Risk factors for lower extremity injuries in elite female soccer players. *The American journal of sports medicine, 42*(4), 940-948.

Nilstad, A., Bahr, R., & Andersen, T. (2014). Text messaging as a new method for injury registration in sports: a methodological study in elite female football. *Scandinavian journal of medicine & science in sports, 24*(1), 243-249.

Nogueira, M., Laiginhas, R., Ramos, J., & Costa, O. (2017). Injuries in Portuguese amateur youth football players: a six month prospective descriptive study. *Acta medica portuguesa, 30*(12), 840-847.

Peterson, L., Junge, A., Chomiak, J., Graf-Baumann, T., & Dvorak, J. (2000). Incidence of football injuries and complaints in different age groups and skill-level groups. *The American journal of sports medicine, 28*(5_suppl), 51-57.

Pfirrmann, D., Herbst, M., Ingelfinger, P., Simon, P., & Tug, S. (2016). Analysis of injury incidences in male professional adult and elite youth soccer players: a systematic review. *Journal of athletic training, 51*(5), 410-424.

Read, P. J., Jimenez, P., Oliver, J. L., & Lloyd, R. S. (2018). Injury prevention in male youth soccer: Current practices and perceptions of practitioners working at elite English academies. *Journal of sports sciences, 36*(12), 1423-1431.

Rosen, P. v., Frohm, A., Kottorp, A., Friden, C., & Heijne, A. (2017). Too little sleep and an unhealthy diet could increase the risk of sustaining a new injury in adolescent elite athletes. *Scandinavian journal of medicine & science in sports, 27*(11), 1364-1371.

Sampson, J. A., Fullagar, H., & Murray, A. (2017). Evidence is needed to determine if there is a better way to determine the acute: chronic workload. *Br J Sports Med, 51*(7), 621-622.

Schmidt-Olsen, S., Bünemann, L., Lade, V., & Brassøe, J. (1985). Soccer injuries of youth. *British Journal of Sports Medicine, 19*(3), 161-164.

Schwellnus, M., Soligard, T., Alonso, J.-M., Bahr, R., Clarsen, B., Dijkstra, H. P., . . . Hutchinson, M. R. (2016). How much is too much?(Part 2) International Olympic Committee consensus statement on load in sport and risk of illness. *Br J Sports Med, 50*(17), 1043-1052.

Smith, D. J. (2003). A framework for understanding the training process leading to elite performance. *Sports medicine, 33*(15), 1103-1126.

Soligard, T., Schwellnus, M., Alonso, J.-M., Bahr, R., Clarsen, B., Dijkstra, H. P., . . . Hutchinson, M. R. (2016). How much is too much?(Part 1) International

Olympic Committee consensus statement on load in sport and risk of injury. *Br J Sports Med, 50*(17), 1030-1041.

Stølen, T., Chamari, K., Castagna, C., & Wisløff, U. (2005). Physiology of soccer. *Sports medicine, 35*(6), 501-536.

Thornton, H. R., Delaney, J. A., Duthie, G. M., & Dascombe, B. J. (2017). Importance of Various Training-Load Measures in Injury Incidence of Professional Rugby League Athletes. *International Journal of Sports Physiology and Performance, 12*(6), 819-824.

Van Mechelen, W., Hlobil, H., & Kemper, H. C. (1992). Incidence, severity, aetiology and prevention of sports injuries. *Sports medicine, 14*(2), 82-99.

Vanrenterghem, J., Nedergaard, N. J., Robinson, M. A., & Drust, B. (2017). Training load monitoring in team sports: a novel framework separating physiological and biomechanical load-adaptation pathways. *Sports medicine, 47*(11), 2135-2142.

Watson, A., Brickson, S., Brooks, A., & Dunn, W. (2016). Subjective well-being and training load predict in-season injury and illness risk in female youth soccer players. *Br J Sports Med*, bjsports-2016-096584.

Weiss, K. J., Allen, S. V., McGuigan, M. R., & Whatman, C. S. (2017). The Relationship Between Training Load and Injury in Men's Professional Basketball. *International Journal of Sports Physiology and Performance, 12*(9), 1238-1242.

Williams, S., West, S., Cross, M. J., & Stokes, K. A. (2017). Better way to determine the acute: chronic workload ratio? *Br J Sports Med, 51*(3), 209-210.

Windt, J., & Gabbett, T. J. (2017). How do training and competition workloads relate to injury? The workload—injury aetiology model. *Br J Sports Med, 51*(5), 428-435.

Wrigley, R., Drust, B., Stratton, G., Scott, M., & Gregson, W. (2012). Quantification of the typical weekly in-season training load in elite junior soccer players. *Journal of sports sciences, 30*(15), 1573-1580.

Table summary

Table 8: Overview of a selected group of studies that have investigated injury incidence among youth football players.

Table 9: Overview of studies that have investigated the ACWR-injury relationship in football.

Table 10: Incidence rate per 1000 exposure hours.

Table 11: Injury locations, categorised by injury mechanism.

Table 12: Abbreviations for the four different calculated ACWR-variables.

Table 13: The analysis of the four different ACWR-variables with Tl-categories compared with reference category. The number of injury incidents and incidence is presented for each respective TL-category as well as OR with 95% CI for each category compared to the reference category.

Table 14: Studies investigated the TL-injury relationship using an ACWR 1:4 RA. TL-data categories and injury definitions are presented for each study. All results from the studies were stated as statistically significant results.

Figure summary

Abbreviations

ACWR	Acute:chronic workload ratio
AM	Ante meridiem
AU	Arbitrary units
BMI	Body mass index
CI	Confidence interval
CR-10	Category rating scale
ECIS	Elite Club Injury Study
EWMA	Exponentially weighted moving averages
FIFA	Fédération Internationale de Football Association
GPS	Global positioning system
HR	Heart rate
TL	Training load
NFF	Norges fotballforbund
NIH	Norwegian School of Sports Science
NSD	Norsk senter for forskningsdata
OSTRC	Oslo Sports Trauma Research Centre
OR	Odds ratio
PM	Post meridiem
RA	Rolling averages
REK	Regional ethical committee
RPE	Rating perceived exertion
SMS	Short message service
SD	Standard deviation
sRPE	Session rating of perceived exertion
UEFA	Union Of European Football Association

Appendix

I	Request for participation in a research project
II	Approval: The Regional Ethics Committee
III	Approval: Norwegian Centre for Data Research

Appendix I – Request for participation in a research project

NIH Senter for idrettsskadeforskning
NORGES IDRETTSHØGSKOLE

Forespørsel om deltagelse i forskningsprosjekt.

Påvirker treningsbelastning skader og sykdom i elite juniorfotball?

Bakgrunn for prosjektet

Fotballspillere av begge kjønn trener mye på juniornivå, 16-19 år. I tillegg til å trene med sitt eget lag, deltar de ofte på mange andre arenaer som skoletrening, landslag og eldre lag. Samtidig har tidligere undersøkelser vist at dårlig styring av individuell treningsbelastning gir økt risiko for sykdom og skade. De fleste spillere opplever fravær fra trening og kamp grunnet skade i junioralder. Dette medfører ofte dårligere prestasjoner både rett i etterkant av skadeperioden, men kan også påvirke den langsiktige utviklingen som fotballspiller. Skade- og sykdomsomfanget i norsk juniorfotball er tidligere ikke undersøkt, og vi ønsker derfor å kartlegge dette ved en studie over 15 uker. I tillegg til skade- og sykdomsinformasjon ønsker vi å vite hvor mye og hvor intensivt juniorspillere trener. Resultatene i denne studien vil danne grunnlag for vår skadeforebyggende modell som vi skal undersøke effekten av gjennom 2018-sesongen.

Senter for idrettsskadeforskning har som formål å forebygge skader og andre helseproblemer i idrett gjennom et langsiktig forskningsprogram med fokus på risikofaktorer, skademekanismer og skadeforebyggende tiltak. Hovedfokuset er skader i håndball, fotball, ski og snowboard. Denne studien er en viktig brikke i arbeidet med å redusere omfanget av skader og sykdom i fotball.

Gjennomføring av prosjektet

Vi ønsker at du som spiller i G-19 nasjonal serie, G-19 interkrets eller J-19 1.divisjon deltar i denne undersøkelsen, og deltakelsen er frivillig. Det vil kreves av deg at du en gang per dag rapporterer varighet og hvordan du selv opplever intensiteten fra hver fotballøkt og fotballkamp, i tillegg til din helsestatus. Metoden for innsamlingen vil være en SMS-basert spørreundersøkelse. Undersøkelsen vil gå over 15 uker i fotballsesongen 2017.

Hva skjer med informasjonen om deg?

I etterkant av undersøkelsen vil vi analysere dataene for å se hvor ofte juniorspillere er plaget av skade eller sykdom, samt om det har en sammenheng med treningsbelastning. Informasjonen som registreres om deg vil kun brukes slik som beskrevet i hensikten med studien. Alle opplysningene vil bli behandlet uten navn og fødselsnummer eller annen direkte gjenkjennende informasjon. Dataene vil bli behandlet konfidensielt, kun brukes til forskning og vil bli anonymisert ved prosjektets slutt, 01.11.2017. Alle som deltar i gjennomføring av prosjektet og forskere som benytter dataene har taushetsplikt.

Angrer du?
Det er frivillig å delta i undersøkelsen. Du kan når som helst og uten å oppgi noen grunn trekke deg fra undersøkelsen. Dersom du ønsker å delta, undertegner du samtykkeerklæringen. Om du nå sier ja til å delta, kan du senere trekke tilbake ditt samtykke.

Spørsmål?
Ring gjerne til stipendiat Torstein Dalen, tlf.: 938 41 844 dersom du har spørsmål om prosjektet, eller send e-post til torstein.dalen@nih.no.

SAMTYKKEERKLÆRING

Jeg har mottatt skriftlig og muntlig informasjon om studien ***"Utvikling av en modell for treningsplanlegging for å redusere skader og sykdom i elite juniorfotball"***.

Jeg er klar over at jeg kan trekke meg på et hvilket som helst tidspunkt.

....
Sted Dato

....
Underskrift spiller

....
Navn (blokkbokstaver)

....
Adresse

....
Mobiltelefon

....
E-post adresse

Appendix II – Approval: The Regional Ethics Committee

REK
REGIONALE KOMITEER FOR MEDISINSK OG HELSEFAGLIG FORSKNINGSETIKK

Region:	**Saksbehandler:**	**Telefon:**	**Vår dato:**	**Vår referanse:**
REK sør-øst	Tove Irene Klokk	22845522	22.06.2017	2017/1015/REK sør-øst A
			Deres dato:	**Deres referanse:**
			09.05.2017	

Vår referanse må oppgis ved alle henvendelser

Torstein Dalen
Seksjon for idrettsmedisin / Senter for idrettsskadeforskning

2017/1015 Treningsbelastning sin påvirkning på skader og sykdom i elite-JR fotball

Forskningsansvarlig: Norges idrettshøgskole
Prosjektleder: Torstein Dalen

Vi viser til søknad om forhåndsgodkjenning av ovennevnte forskningsprosjekt. Søknaden ble behandlet av Regional komité for medisinsk og helsefaglig forskningsetikk (REK sør-øst) i møtet 08.06.2017. Vurderingen er gjort med hjemmel i helseforskningsloven § 10.

Prosjektbeskrivelse (revidert av REK)

Formålet med prosjektet er todelt: det første formålet er å undersøke omfanget av skader og sykdom hos fotballspillere i alderen 16-19 år, og det andre formålet er å undersøke hvilke parametre for treningsbelastning som eventuelt har sammenheng med risiko for sykdom eller skade.

Det skal rekrutteres 100 forsøkspersoner, fordelt på 3 fotballag av hvert kjønn i alderen 16-19 år. Deltakerne skal rekrutteres via støtteapparatet i klubbene, og det skal innhentes skriftlig samtykke. Deltakerne skal en gang per dag rapportere varighet og hvordan de selv opplever intensiteten av hver fotballøkt og fotballkamp, via en applikasjon for smarttelefon. I tillegg skal de en gang i uken besvare OSTRC (Oslo Sports Trauma Research Center) sitt spørreskjema Questionnaire on health problems. Informasjonen vil samles over en periode på 15 uker. Hovedutfallsmålet er prevalens av helseproblemer og hvordan treningsbelastning påvirker forekomsten av helseproblemer.

Vurdering

Formålet med prosjektet, slik det fremkommer av søknad og protokoll, er å undersøke sammenhengen mellom treningsbelastning og skader og sykdom hos elite-juniorspillere i fotball.

Prosjektet har etter komiteens vurdering ikke som formål å skaffe til veie ny kunnskap om helse og sykdom, og faller dermed utenfor helseforskningslovens virkeområde. Helseforskningsloven gjelder for medisinsk og helsefaglig forskning, definert som forskning på mennesker, humant biologisk materiale og helseopplysninger, som har som formål å frambringe ny kunnskap om helse og sykdom, jf. helseforskningsloven §§ 2 og 4a. Formålet er avgjørende, ikke om forskningen utføres av helsepersonell eller på pasienter eller benytter helseopplysninger.

Prosjekter som faller utenfor helseforskningslovens virkeområde kan gjennomføres uten godkjenning av REK. Det er institusjonens ansvar på å sørge for at prosjektet gjennomføres på en forsvarlig måte med hensyn til for eksempel regler for taushetsplikt og personvern.

Vedtak

Prosjektet faller utenfor helseforskningslovens virkeområde, jf. § 2, og kan derfor gjennomføres uten godkjenning av REK.

Klageadgang

Komiteens vedtak kan påklages til Den nasjonale forskningsetiske komité for medisin og helsefag, jf. helseforskningsloven § 10, 3 ledd og forvaltningsloven § 28. En eventuell klage sendes til REK Sørøst A. Klagefristen er tre uker fra mottak av dette brevet, jf. forvaltningsloven § 29.

Med vennlig hilsen

Knut Engedal
Professor dr. med.
Leder

Tove Irene Klokk
Rådgiver

Kopi til: torstein.dalen@nih.no, Norges idrettshøgskole ved øverste administrative ledelse: postmottak@nih.no

Appendix III – Approval: Norwegian Centre for Data Research

NSD

Torstein Dalen
Seksjon for idrettsmedisinske fag Norges idrettshøgskole
Postboks 4014 Ullevål Stadion
0806 OSLO

Vår dato: 30.06.2017 Vår ref: 54857 / 3 / AMS Deres dato: Deres ref:

TILBAKEMELDING PÅ MELDING OM BEHANDLING AV PERSONOPPLYSNINGER

Vi viser til melding om behandling av personopplysninger, mottatt 26.06.2017. Meldingen gjelder prosjektet:

54857	*Treningsbelastning sin påvirkning på skader og sykdom i elite juniorfotball.*
Behandlingsansvarlig	*Norges idrettshøgskole, ved institusjonens øverste leder*
Daglig ansvarlig	*Torstein Dalen*

Personvernombudet har vurdert prosjektet, og finner at behandlingen av personopplysninger vil være regulert av § 7-27 i personopplysningsforskriften. Personvernombudet tilrår at prosjektet gjennomføres.

Personvernombudets tilråding forutsetter at prosjektet gjennomføres i tråd med opplysningene gitt i meldeskjemaet, korrespondanse med ombudet, ombudets kommentarer samt personopplysningsloven og helseregisterloven med forskrifter. Behandlingen av personopplysninger kan settes i gang.

Det gjøres oppmerksom på at det skal gis ny melding dersom behandlingen endres i forhold til de opplysninger som ligger til grunn for personvernombudets vurdering. Endringsmeldinger gis via et eget skjema, http://www.nsd.uib.no/personvernombud/meld_prosjekt/meld_endringer.html. Det skal også gis melding etter tre år dersom prosjektet fortsatt pågår. Meldinger skal skje skriftlig til ombudet.

Personvernombudet har lagt ut opplysninger om prosjektet i en offentlig database, http://pvo.nsd.no/prosjekt.

Personvernombudet vil ved prosjektets avslutning, 15.10.2017, rette en henvendelse angående status for behandlingen av personopplysninger.

Vennlig hilsen

Kjersti Haugstvedt

Anne-Mette Somby

Kontaktperson: Anne-Mette Somby tlf: 55 58 24 10
Vedlegg: Prosjektvurdering

Dokumentet er elektronisk produsert og godkjent ved NSDs rutiner for elektronisk godkjenning.

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