

*Internal and external load measures as
predictors of overuse injury risk in
professional football players*

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ABBREVIATIONS

TL	Training load
ITL	Internal Training Load
ETL	External Training Load
sRPE	Session Rating of Perceived Exertion
GPS	Global Positioning System
MTU	Muscle Tendon Unit
AWL	Acute Workload
CWL	Chronic Workload
ACWLR	Acute:chronic Workload Ratio
HIS	High-intensity Sprints
TDC	Total Distance Covered
PSL	Premier Soccer League
UEFA	Union of European Football Associations
RTP	Return To Play
RTT	Return To Train

DEFINITIONS

Distance (m)	All distance covered in walking, jogging, running and high speed running
SRPE (arbitrary units)	Sessions Rating of Perceived Exertion x session duration
High intensity sprints	Distance above 24km p/h, for 15-30 meters

ABSTRACT

Background

Football is the most popular sport worldwide. Football has grown into a faster, intensive and more competitive game with a substantial increase in technical and physical demands. To reach the peak demands of match play, extensive training is necessary to improve performance and to reach the top level in professional football. Inadequate training loads prevent optimal performance adaptations, place the player at higher risk of being underprepared and may increase the risk of overuse injuries. Determining an optimal training load that improves performance and decreases the risk of overuse injuries is important. Therefore, monitoring and understanding individual responses to training loads are necessary. To date there is limited research regarding prediction of risk of overuse injuries with respect to optimal TL in professional football players.

Aim

To describe the pattern of injuries and determine the influence of load metrics and injury risk in South African professional football. The total GPS distance covered, the number of GPS measured high-intensity sprints and session Rating Perceived Exertion load and the effects on the risk of developing an overuse injury in professional football players.

Objectives

(1) To determine the relationship between total GPS distance (m) covered, ACWLR and overuse injuries in a full competitive season. (2) To determine the relationship between GPS measured high-intensity sprints, ACWLR and overuse injuries in a full competitive season. (3) To determine the relationship between session rating of perceived exertion, ACWLR and overuse injuries in a full competitive season. (4) To determine the overuse injury risk per playing position (defenders, midfielders and attackers). (5) To determine the patterns of injury during a full competitive season. (6) To determine the effect of the internal load (sRPE) and external load (GPS) in a congestion week compared to a normal week on overuse injury risk.

Methods

Data was collected from 32 professional football players in the first and reserve team over one full competitive Premier Soccer League season (2016/17). Training load metrics were assessed using the acute:chronic workload ratio (ACWLR) to predict overuse injury risk within the team. The relationship between total GPS distance (m) covered (TDC), GPS measured high-intensity sprints (HIS), session rating of perceived exertion (sRPE) and ACWLR and overuse injuries was determined. Overuse injuries were described based on frequency, anatomical position and injury type as well as with regards to playing position (defenders, midfielders and attackers). The effect of a congestion week on overuse injury risk was also determined.

Results

No significant outcomes were recorded when predicting overuse injuries for the whole team, with regards to average TDC, HIS and sRPE ACWLR. Overuse injuries may be predicted when monitoring the individual player loads, thereby taking into account the peak demands of match play per playing position. Large difference between TDC and HIS and large increases or decreases (20%) within weeks may increase the risk of overuse injuries. Hamstrings and groins injuries are the most common injuries sustained and defenders sustained the most overuse injuries within the team relative to exposure time. Congestion weeks did not predict overuse injury risk.

1.LITERATURE REVIEW

1.1 Introduction

Football is worldwide the most popular sport with an estimated 265 million registered players (Kirkendall, Junge, & Dvorak, 2010). Over the past few years, the sport has grown into a faster, intensive and more competitive game with a substantial increase in technical and physical demands (Bowen, Gross, Gimpel, & Li, 2016; Abbott, Brickley, & Smeeton, 2017). To reach these demands, extensive training is necessary to improve performance and to reach the top in professional football (Brink, et al., 2010). Training loads below or above the demands of professional football prevent optimal performance adaptations, places the player at a higher risk of being underprepared and may increase the risk of overuse injuries (Bowen, et al., 2016; Hulin, Gabbett, Lawson, Caputi, Sampson, 2016). Determining the optimal training load that improves fitness and performance, without increasing the likelihood of sustaining an injury is important (Hulin, et al., 2016). Therefore, monitoring and understanding individual responses to training sessions are necessary to ensure an optimal training load and therefore reducing the risk of developing an overuse injury (Bourdon, et al., 2017; Bowen, et al., 2016).

Data was sourced from sports medicine and science literature using searches on PubMed. Keywords used in the search included *“football”, “injury”, “overuse injuries”, “lower extremity overuse injury”, “training load”, “peak demands”, “internal and external training load”, “internal and external injury risk factors”, “congestion week”, “monitoring training load”, “acute and chronic work load”, acute:chronic workload ratio”, “session Rating of Perceived Exertion”, “Global Positioning System”*.

Training load (TL) is the amount of work or exertion completed by an athlete during training (Wallace, Slattery, & Coutts 2014; Halson 2014). Training load can be categorized in accordance with the method used to quantify intensity and can be described as either internal training load (ITL) or external training load (ETL) (Wallace, et al., 2014; Scott et al., 2013). ITL is the athlete’s response to training or the measured physiological stress on the athlete imposed by the training and can be measured through various modalities such as heart rate (HR), HR-based Banister’s TRaining IMPulse (TRIMP) or perception of effort (Wallace, Slattery, & Coutts 2014; Scott et al., 2013; Brink, Nederhof, Visscher, Schmikli, & Lemmink, 2010; Impellizzeri,

Rampinini, & Marcora, 2005; Impellizzeri, et al., 2004; Wallace, Slattery, & Coutts 2014).

Session Rating of Perceived Exertion (sRPE) is a valid and reliable measurement (Scott et al., 2013) and together with heart rate, the most commonly used measurements to determine ITL in field sports such as football (Scott et al., 2013). sRPE is a Compared to blood lactate concentrations and heart rate, sRPE provides a valid estimation of exercise intensity (Dunbar, et al., 1992; Impellizzeri, et al., 2004; Foster, 1998; Gabbett, & Domrow, 2007). However, sRPE has the limitation that it does not differentiate between different training sessions (Soligard, et al., 2016; Brink, et al., 2010). Additionally, considering the fact that sRPE is subjective, and does not predict overuse injuries on its own, combining it with an objective external measurement will ensure the reliability of the measurements (Wallace, et al., 2014; Wallace, et al., 2009; Brink, et al., 2010).

By using an external measurement in combination with an internal measurement, prediction of overuse injuries will be possible (Wallace, et al., 2014). Current technological developments make it possible to quantify and monitor ETL by using Global Positioning System (GPS) (Wallace, et al., 2014). GPS collects external data regarding the work performed by the athlete as prescribed by the coach. These are outcomes such as duration in minutes, speed, distance or the number of high-intensity sprints (Wallace, et al., 2014; Impellizzeri, Rampinini, & Marcora, 2005; Impellizzeri, et al., 2004; Scott et al., 2013; Brink et al., 2010). Additionally, the most reliable determinants of ETL are the number of training sessions as duration in minutes (Brink et al., 2010) and total distance covered (Scott et al., 2013). The average running speed and distance covered has been used to quantify physical performance in team sports (Scott et al., 2013). In addition, the accelerometers used to calculate players load have been shown to be reliable during high-intensity sprints in Australian football (Scott et al., 2013) and football (Jennings et al., 2010). Conclusively, ITL and ETL measurements should be quantified separately and assessed in relation to one other (Scott et al., 2013). Combining the two different measurements will provide data, which the coaching and medical staff can use to determine the response of the training (Scott et al., 2013).

Assessment of the ITL and ETL responses of training is important in professional football, as the external load is generally the same for each football player (Impellizzeri, et al., 2005;

Impellizzeri, et al., 2004; Wallace et al., 2009; Halson 2014). As training sessions are performed as a team and are rarely player or position-specific, some players may not obtain sufficient training stimulus to improve their fitness levels, whilst others may be overloaded during training (Alexiou, & Coutts, 2008). For instance, central and wide midfielder generally cover greater total distance compared to full-backs, central defenders, and attackers (Brandley, et al., 2009). Wide midfielders also cover a greater distance of high-intensity sprints compared to defenders, full-backs, central midfielders, and attackers. Central defenders cover the least high-intensity sprints than all other positions (Brandley, et al., 2009). In other words, as midfielders perform more high-intensity sprints during match play, compared to defenders they may be under loaded during training sessions. In contrast, defenders do not perform as many sprints as attackers and do not cover as many kilometers as midfielders, they may be overloaded during an average training session (Abbott, Brickley, & Smeeton, 2017). In other words, the individual peak demands of match play should be determined and averages should be prescribed during training sessions. If the average per team is prescribed during training sessions, some players may not be exposed to an appropriate level of training stimulus, may subsequently experience increased fatigue and may have reduced performance (Alexiou, & Coutts, 2008; Abbott, Brickley, & Smeeton, 2017). To improve these limitations during team-based training sessions, monitoring individual's response to TL is necessary (Alexiou, & Coutts, 2008).

The effect of training on overall performance depends on the individual players current training status i.e. there is a greater training stimulus expected in the beginning of the season with the same TL when the overall training status is low (Brink et al., 2010). As the player adapts to the TL, a higher acute training stimulus is required to elicit a further response (Brink et al., 2010). In addition, it is important to measure performance as an outcome in monitoring TL and recovery (Brink et al., 2010). The performance of a player depends on the relationship between fitness and fatigue. Training must be optimized so that it maximizes performance and concurrently, minimizes the risk of excessive fatigue, overtraining and the risk of developing an overuse injury (Gabbett, & Domrow, 2007). Evidence shows that there is a generally positive relationship between higher training intensity and volume and performance (Gabbett, & Domrow, 2007). However, negative adaptations to training are also dose related with an increase in the incidence of overtraining and underperformance during peak demands of performance (Gabbett, & Domrow, 2007). There is also evidence suggesting that there is a relationship between higher TL and

intensity and the number of injuries in team players (Gabbett, & Domrow, 2007). It is therefore important to monitor the TL - performance relationship to determine the optimum TL to improve performance and to predict and prevent injuries (Gabbett, & Domrow, 2007; Alexiou, & Coutts, 2008; Leventer, et al., 2016).

Injuries are common in professional football (Hägglund, Waldén, & Ekstrand, 2013; Junge, et al., 2004). The incidence of injury varies depending on the type of match or tournament and occur four times more often in matches compared to training (Junge, & Dvorak, 2015).

However, the study by Fuller (2018), concluded, that teams that are more successful in competition sustain more injuries during match play, in contrast with teams that are less successful in competition. These teams sustain more injuries during training sessions (Fuller, 2018). As training sessions are prescribed by the coaching staff, they can influence and change the nature and number of training sessions. In contrast, the demands of match play are not influenceable and no one can influence how the opposing team plays during a match (Fuller, 2018).

Most football injuries are caused by contact with another player, but more than a quarter of the injuries are noncontact (Junge, & Dvorak, 2015). A research conducted in Europe included team from 10 different countries over eight seasons (Ekstrand, Hägglund, & Waldén, 2011). The research used a total of 1 175 000 training and competition hours (Ekstrand, Hägglund, & Waldén, 2011), and concluded that the incidence and mechanism of injury varied during the course of the match (Junge, & Dvorak, 2015). Fewer injuries occur in the first 15 minutes of each half, and an increasing number of injuries occur towards the end of each half (Junge, & Dvorak, 2015). Although the epidemiology of injury is extensively researched in professional football in Europe (Junge, & Dvorak, 2015; Ekstrand, Hägglund, & Waldén, 2011), there is limited research on this topic in Africa and South Africa respectively (Bayne, et al 2017).

The studies by Calligeris, Burgess, and Lambert (2015) and Bayne, et al (2017) are the most recent studies on injury incidence in South African professional football. The study by Calligeris, Burgess, and Lambert (2015) demonstrated 130 injuries over a full competitive season within a professional South African football team. The overall injury rate was 13.4 per 1 000 playing hours (Calligeris, Burgess, and Lambert (2015) which is higher compared to 2.70-8.70 injuries

per 1 000 playing hours on average in Europe (Ekstrand, Hägglund, & Waldén, 2011; Junge, et al., 2004). Interestingly, Nigerian football players sustain even more injuries compared to South African football players (Akodu, et al 2012). The injury rate in Nigeria is 55.2 per 1 000 playing hours (Akodu, et al 2012).

In addition, European football players sustain on average 0.6- 2.0 injuries per season, which results in 50-55 injuries per team per season (Ekstrand, Hägglund, & Waldén 2009). This is similar to South African football players (Calligeris, Burgess, and Lambert, 2015). Thighs and ankles were the most commonly affected body part in the study by Calligeris, Burgess, and Lambert (2015). This is somewhat in contrast with European studies, where hamstring, groins and calf muscles are more often affected than ankles (Ekstrand, Hägglund, & Waldén, 2011; Junge, & Dvorak, 2015). Nevertheless, the lower extremity is in all studies the most commonly affected in professional football players (Akodu, et al., 2012; Calligeris, Burgess, and Lambert, 2015; Bayne, et al., 2017; Ekstrand, Hägglund, & Waldén, 2011).

It is not surprising that the lower extremity is most often affected, due to the continual load through the pubic area, placed on the leg during training and competition. Ninety percent of these injuries affect the muscle tendon unit (Hägglund, Waldén, & Ekstrand, 2013; (Ekstrand, Hägglund, & Waldén, 2011). The hamstrings are with 37% the most commonly affected muscles, followed by adductors (23%), quadriceps (19%) and calf muscles (13%) (Ekstrand, Hägglund, & Waldén, 2011). Muscle strains are the most common type of injury and affect the posterior side (e.g. hamstrings) more often than the anterior side (e.g. quadriceps) (Hägglund, Waldén, & Ekstrand, 2013). Consequently, these muscle injuries result in more than 25% of training sessions and competitions missed by players (Hägglund, Waldén, & Ekstrand, 2013; Ekstrand, Hägglund, & Waldén, 2011).

An injury is defined as any pain or discomfort experienced by a player during a training session or match that prevented the player from continuing playing (Gabbett, & Domrow, 2007; Gabbett, 2003). Overuse injuries are injuries without a specific, identifiable event as a cause and occurring gradually over time (Clarsen, Myklebust, & Bahr, 2013). A 'time-loss' injury is defined as any pain or discomfort experienced by a player during a match or training session, whereby the player is not able to take full part of training or competition the following day (Gabbett, 2004;

Fuller, et al., 2006). In the case of a medical attention injury, a player requires medical treatment but returns to training and play within the next 24-hours (Ekstrand, Junge, Andersen, & McCrory, 2006). Although overuse injuries are less common than acute injuries, overuse injuries may be preventable if the individual players TL is monitored and adjusted in time throughout training and match play, however, minimal research has assessed this hypothesis.

Most studies calculate injury exposure by multiplying the number of players by the session duration (Bowen, et al., 2016; Ekstrand, Junge, Andersen & McCrory, 2006). Overuse injury incidence is calculated by dividing the total number of overuse injuries by the overall exposure, and expressed as rates per 1 000 playing hours (Bowen, et al., 2016; Clarsen, Myklebust, & Bahr, 2013; Ekstrand, Junge, Andersen, & McCrory, 2006; Soligard, 2016). Injury exposure is used in combination with the acute:chronic load ratio. The ratio is an expression of workload (WL) and to classify the relationship between TL and injury risk (Soligard, et al., 2016). The ratio describes the acute training load (previous week) in combination with the chronic training load (rolling 4 week average) (Soligard, et al., 2016). It is calculated by dividing acute workload (AWL) by the chronic workload (CWL). An acute:chronic load ratio greater than 1 represents an AWL greater than CWL. A player is considered well-conditioned if the chronic and the acute load are both progressively increased (Halson, 2014).

Nevertheless, there is insufficient research with respect to the relationship between TL and overuse injury risk in professional football. Additionally, there is almost no research investigating the comparison between acute and chronic workload derived from sRPE and GPS associated with overuse injuries during a full competitive football season (Hulin, Gabbett, Lawson, Caputi, & Sampson, 2016). Therefore, this research will concurrently investigate the effect of ITL and ETL on the risk of developing an overuse injury in professional football players.

2. TRAINING AND COMPETITION LOAD IN FOOTBALL

The mean distance covered during a football match is between 10 000 and 11 000 meters, with peaks up to 14 000 meters (Bengtsson, et al., (2013). A quarter of the total distance is usually composed of high-intensity sprints (Bengtsson, et al., 2013). High- intensity sprints are variably defined in research, but are generally defined as sprints exceeding 24km/h for 15-30 meters

(Hulin, et al., 2016; Murray et al., 2016; Varley et al., 2013; Johnston et al., 2014; Cunniffe et al., 2009; Scott, et al., 2013). A high number of performed high-intensity sprints during a match may cause compromised physical ability, such as leg strength, sprinting ability and vertical jump height (Bengtsson, et al., 2013). As a result, it may affect high-intensity sprint ability and prevents players from reaching their optimal speeds if they have not been given sufficient time to recover (Bengtsson, et al., 2013). Taking this into account, it may take up to 72 hours for a player to fully recover following a football match and to be able to reach the same performance level (Bengtsson, et al., 2013).

There is generally less than 72 hours recovery time when playing two matches a week (Bengtsson, et al., 2013). This may result in changes in lower extremity biomechanics, and are shown to alter with muscle fatigue (Bengtsson, et al., 2013). Fatigued muscles have been shown to be unable to absorb sufficient energy before an injury occurs and thus it is possible that structural and biomechanical changes may result in the football players being more prone to muscle injuries in the first 72 hours following a match (Bengtsson, et al., 2013). Football teams with large squads have the advantage that they can rotate individual players and thus avoid players from developing too much fatigue, being overloaded and therefore being at a higher risk of developing overuse injuries (Bengtsson, et al., 2013).

Factors such as playing surface and home match or away match will influence injury risk (Bengtsson, Ekstrand, Waldén, & Häggglund, 2013). Home teams take more shots at goal, have greater ball possession time and are more likely to win the match compared to the away team (Bengtsson, et al., 2013). The studies by Ekstrand, et al., (2004) and Häggglund, et al., (2009), concluded that there is a significantly higher possibility that two or more injuries occur during the match are concomitant with a subsequent loss or draw of the match. Similar conclusions are made when home matches are compared with away matches (Ekstrand, et al., 2004; Häggglund, et al., 2009).

The study by Bengtsson et al., (2013) investigated the injury rates of 6 010 competitive matches in the Union of European Football Associations (UEFA) Champions League and found a decrease in injury rates in away matches compared to home matches. In addition, the chance of ending the match with a loss or draw was increased in matches where two or more injuries

occurred compared to matches with no injuries (Bengtsson et al., 2013). The study by Bengtsson et al. (2013) demonstrated that football players perform less high-intensity sprints when they were winning the match compared to when losing the match. This is reinforced by evidence that the high-intensity distance is significantly shorter for the winning team compared to the losing team (Dupont et al., 2010). This may be explained by the fact that the winning team has to keep the ball, whereas the losing team has to work harder and must therefore increase the high-intensity sprints (Dupont et al., 2010). It is therefore hypothesized that the reduction in high-intensity sprints may result in a decreased injury risk (Bengtsson et al., 2013).

In addition, there is a significant difference in injury type based on match location, with a higher incidence of muscle and tendon injuries compared to joint or ligament injuries in home matches (Bengtsson et al., 2013). This may be the result of different factors affecting injury risk.

3. INJURY RISK

Injury risk is caused and affected by many factors including; intrinsic and extrinsic risk factors, playing position, congestion week, environmental conditions, and training load. However, the most common risk factor for an index injury or a recurrent injury is a prior injury (Arnason, et al., 2004; Dvorak, et al., 2000; Hägglund, Waldén, & Ekstrand, 2013; Meeuwisse, et al., 2007).

3.1. Prior injury

The most common risk factor for an injury is prior injury (Arnason, et al., 2004; Dvorak, et al., 2000; Hägglund, Waldén, & Ekstrand, 2013). On average 77% of the players in one team sustain an injury during a competitive season (Hägglund, Waldén, & Ekstrand, 2006). Whereby 87% of these players will reinjure in the following season compared to 48% of the players with no injuries during the preceding season (Hägglund, et al., 2006). This shows that players with an injury may have an almost threefold risk of sustaining an injury in the following competitive season (Hägglund, et al., 2006).

Hamstring injuries are the most common noncontact injury in male football players, representing 12% of all injuries (van Dyk, et al., 2018). In addition, prior hamstring injury, especially when rehabilitation was inadequate, is a significant risk factor for new hamstring injuries (Engebretsen, et al., 2010; van Dyk et al., 2018). Players that previously injured their hamstring have more than

twice as much risk to re-injure their hamstring (Engebretsen, et al., 2010). Potential predictors of increased hamstring injury risk include hamstring length, strength deficits, imbalances (Engebretsen, et al., 2010) and range of motion measured by the straight-leg-raise (van Dyk, et al., 2018). The study by Croisier, et al., (2008) identified that players without preseason hamstring strength imbalances have a reduced risk of hamstring injuries compared to players who have imbalances. In addition, untreated hamstring imbalances resulted in a 4-fold higher risk of hamstring injury in comparison with a normal strength (Croisier, et al., 2008).

Previous injury is not only a significant risk factor for hamstring injuries but also for groin and quadriceps strains and knee injuries, as well as ankle sprains and overuse injuries in general (Hägglund, et al., 2006). Additionally, prior groin, knee or hamstring overuse injuries are associated with a two to three-fold increase in the risk of a similar overuse injury at the same leg (Hägglund, et al., 2006; Arnason, et al., 2004; Croisier, et al., (2008). The reported recurrence of groin injury (30-51%), hamstring injury (12-43%), and ankle sprain (30-40%) in football is high (Woods, et al., 2004). This may be a result of inadequate rehabilitation, premature return to play (RTP), and excessively high increases in training loads (Woods, et al., 2004; Croisier, et al., 2008; Engebretsen, et al., 2010; Hägglund, et al., 2013; Hägglund, et al., 2006).

3.2. Intrinsic and extrinsic risk factors

Risk factors can be divided into intrinsic (individual) and extrinsic (environmental) factors (Dvorak, et al., 2000; Arnason, et al., 2004; Waldén et al., 2013; Meeuwisse, et al., 2007). Intrinsic factors are biological or psychosocial characteristic. These include; sex, age, body mass index (BMI), height and weight, flexibility (ligament laxity and muscle tightness), malalignment, leg length discrepancy, decreased muscle strength or muscle strength imbalances (Dvorak, et al., 2000; Arnason, et al., 2004; Waldén et al., 2013).

Extrinsic factors include the amount of training and number of games played, environmental related factors, such as pitch surface, playing field conditions, equipment, and weather conditions (Dvorak, et al., 2000; Waldén et al., 2013). A factor that is influenceable, and is therefore a very important extrinsic factor is training load, including; warm-up, recovery sessions, duration, intensity, and number of training sessions in general (Dvorak, et al., 2000; Hägglund, et al., 2006; Engebretsen, et al., 2010; Hägglund, et al., 2013; Hägglund, et al., 2006; Meeuwisse, et

al., 2007). High training exposure and competition exposure have a significant effect on hamstring injuries in football players. High training and competition loads include most of the time a high number of high- intensity sprints (HIS) (Hägglund, et al., 2013; Hägglund, et al., 2006; van Dyk, et al., 2018). A high number of high- intensity sprints have been shown to increase the risk of sustaining a hamstring injury (Hägglund, et al., 2006; van Dyk, et al., 2018; van Dyk et al., 2018). However, another important risk factors for sustaining an injury is playing position (Leventer, et al., 2016; Abbott, et al., 2017).

3.3. Playing position

Playing position has a large influence on sustaining an injury (Leventer, et al., 2016; Abbott, et al., 2017). Different positional roles require unique physiological, technical and tactical performances from the individual player (Leventer, et al., 2016). These unique demands may predispose players to greater risk for certain types of injuries (Carling et al., 2010; Dauty, & Collon, 2011; Abbott, et al., 2017). Midfielders and forwards are known to have the highest risk of injuries, followed by defenders and goalkeepers (Carling et al., 2010; Dauty, & Collon, 2011). The study by Morgan, & Oberlander (2001) determined that midfielders sustain most injuries (37.6%) and have the highest incidence of match injuries (Leventer et al., 2016), followed by defenders (29.6%) and forwards (20.5%) (Morgan, & Oberlander (2001). Central-defenders and wing-midfielders sustain the highest injury rate during training (Leventer et al., 2016). As central-defenders are more often engaged in mid-air duels than defenders, they are therefore at a higher risk to sustain an acute contact injury (Ryynänen et al., 2013). In contrast, wing-midfielders are less frequently engaged in mid-air duels but cover a significantly greater HIS distance (Carling et al., 2010; Dauty, & Collon, 2011; Abbott, et al., 2017). Therefore, midfielders may eccentrically overload the muscular-tendon junction and are more prone to sustain overuse injuries compared to defenders (Carling et al., 2010; Dauty, & Collon, 2011).

Goalkeepers appear to suffer from the least overuse injuries of the lower extremity compared to all other positions (Hägglund, et al., 2013; Leventer et al., 2016). It is hypothesized that goalkeepers are less likely to sustain overuse injuries, as they do not have to perform high-intensity sprints and barely cover distance (Hägglund, et al., 2013). Therefore, we have excluded goalkeepers in our analyses.

3.4. Environmental conditions

Several match factors such as match location and weather conditions have an effect on injury risk and rates (Hägglund, et al., 2013; Meeusen, et al., 2013; Laventer, et al., 2016). The study by Waldén, et al., (2013) showed that there was a higher risk of overuse injuries in Scandinavian countries compared to the countries in Southern Europe. The summers in the north of Europe are cool and the winter's cold compared to a Mediterranean climate in the south of Europe (Waldén, et al., 2013). The study by Waldén, et al., (2013) concluded thereby that the risk of overuse injuries in cold weather is much higher than in warm weather. In addition, the German Premier League (Bundesliga) is considered one of the best leagues in professional football worldwide in terms of performance and low injuries incidence (Waldén et al., 2013). It may be assumed that this is partly due to the fact that the weather conditions are generally the same throughout Germany and the temperature changes in the four seasons are not drastic compared to, for instance, South Africa.

Taking the weather conditions and environmental factors in different locations across South Africa into account (such as altitude in Johannesburg, humidity in Durban and temperature difference between Cape Town and Bloemfontein), it can be assumed that this may have a negative effect on injury incidence in South African football players. Given the fact that South African football players are exposed to extreme differences in weather conditions, it can be assumed that these players are more prone to injuries. However, there is no research on South African football to support this assumption.

3.5. Congestion week

Competition typically places greater demands on players compared to training (Soligard, et al., 2016). Competitions accompany a rapid increase in acute load relative to what the player is prepared for (chronic load) (McCall et al., 2014). Consequently, it may contribute to a significant increase in injury rates (Soligard, et al., 2016). In addition, the player is at an even higher risk of sustaining an injury during matches in a congestion week (McCall et al., 2014).

Match congestion is defined as playing two or more matches per week instead of one match per week, whereby there are fewer days of in-between recovery time (McCall et al., 2014). Players

who play two matches within 96 hours are expected to have impaired match-related physical performance (McCall et al., 2014). The study by Dupont et al., (2010) concluded that the distance covered during the first half of the first match in the current week was significantly more compared to the second half. In addition, football players cover less overall distance and less high-intensity sprint distance and reduce their number of performed high-intensity sprints in the second match of the week (Dupont et al., 2010). It can be assumed that the performance of the players is reduced, due to the fact that the recovery time is insufficient to return to prematch levels (Soligard, et al., 2016; Dupont et al., 2010). The study by Dupont, et al., (2010) found a significant increase in injury rate if there were less than three days of recovery time between matches compared to more than six days of recovery time. It can be assumed that 72-96 hours of recovery is not enough to return to prematch levels for maximal strength and sprinting ability (Dupont et al., 2010). Players are therefore at a higher risk to sustain an injury during a match in a congestion week compared to a normal week (Dupont et al., 2010).

In contrast, the incidence of injuries during training in a congestion week is uninfluenced or even reduced (Soligard, et al., 2016). This may be explained by the fact that training sessions in a congestion week is generally less demanding compared to average training sessions, are shorter in duration and consist more of match preparation, which is generally less intense (Soligard, et al., 2016). As there are differences between load in congestion weeks and normal weeks, the TL has a large effect on injury risk.

3.6. Training load

The studies by Blanch, & Gabbett (2016) and Meeusen et al., (2013) concluded that weekly training loads (hours per week and kilometers per week) increases of 5-10% are associated with increased injury risk and increased injury incidence in football players. In addition, there is a lower risk of injuries when the increase in TL is less than 10% (Blanch, & Gabbett, 2016; Meeusen et al., 2013). In other words, the higher the increase of TL, the more injuries football players sustain during a competitive season (Blanch, & Gabbett, 2016; Gabbett, et al., 2014; Meeusen et al., 2013; Woods, et al., 2004). However, Abbott, et al., (2017) recommends high training loads to protect the player against injuries. Thus, the ITL measurements, such as sRPE, should be high but these high loads should be progressively increased and should not exceed a

rate that exposes players to an increased risk of injury.

Sudden changes in TL are associated with increased risk of injury in rugby and football players (Veugelers, et al., 2016; Blanch, & Gabbett, 2016; Meeusen et al., 2013). Rugby and football players that experienced a substantial increase in TL in the previous week, compared with the TL in the current week, are 2.58 times more likely to sustain a muscle injury (Veugelers, et al., 2016; Blanch, & Gabbett, 2016; Meeusen et al., 2013). The odds of injury may be reduced for rugby players undergoing a consistent high TL compared to rugby players undergoing low training loads (Veugelers, et al., 2016). It may be assumed that rugby players exposed to high TL are training within the optimum TL, whereas, rugby players exposed to a low TL, may have inadequate exposure of sufficient TL (Veugelers, et al., 2016). This may result in the player being inadequately prepared for the demands of match play. An average training session should be in accordance with a percentage of the peak demands of match play for the individual player (Abbott, Brickley & Smeeton, 2017). In addition, reducing or keeping the TL at an individual's adequate level and therefore limiting a players' level of fatigue may result in a decreased likelihood of sustaining an injury (Veugelers, et al., 2016; Abbott, Brickley & Smeeton, 2017). However, reducing TL, to encourage physiological adaption may concurrently have a negative effect on fitness level and may likewise increase injury risk (Veugelers, et al., 2016). Large variations in TL, such as imposing a forced rest may have a disadvantageous effect on injury incidence (Veugelers, et al., 2016). The study by Rogalski, et al (2013) discovered that significant week-to-week variation in TL was associated with an increased number of injuries in elite Australian football players (Rogalski, et al., 2013). In other words, players are better able to tolerate a consistent level of TL in combination with prevention of increases of more than 20% per week and within weeks (Veugelers, et al., 2016; Blanch, & Gabbett, 2016; Meeusen et al., 2013; Abbott, Brickley & Smeeton, 2017). In conclusion, determining the balance between overloading and underloading is essential to reduce the risk of developing injuries in general.

4. OVERUSE INJURIES AFFECTED BY TRAINING LOAD

Overuse injuries are injuries whereby the onset and cause of injury is unknown and may occur over time as a result of repetitive micro damage affecting a specific structure (Clarsen, Myklebust, & Bahr, 2013; Difiori, et al., 2014; Waldén, et al., 2005). The incidence of overuse

injuries is reported based on the number of injuries per 1 000 hours of training and match days of each player. These injuries are further categorized according to the site of injury and the days of play missed by the player (Bowen, et al., 2016). In particular, football reports high rates of injury to the lower extremity such as the hip/groin, knee, ankle/foot, thigh, calf, quadriceps, and hamstring (Bowen, et al., 2016). Severity is defined as per days missed. A minimal injury is defined as 1–3 days of football activity missed, mild (4–7 days), moderate (1–4 weeks) or severe (4+ weeks) (Bowen, et al., 2016).

Sustaining an overuse injury may be as a result of repeated submaximal loading of the musculoskeletal system in combination with insufficient recovery (Difiori, et al., 2014; Waldén, et al., 2005). Inadequate recovery may result in musculoskeletal maladaptation with clinical symptoms and functional limitations, affecting the performance (Soligard, et al., 2016; Difiori, et al., 2014; Waldén, et al., 2005). Overuse injuries often occur in sports that require long training sessions with monotonous routine, repetitive movements and technical aspects, such as in football (Bahr, 2009). These injuries occur mainly at a professional level of football where the training and competition loads are very high (Clarsen, Myklebust, & Bahr, 2013). Poorly managed training and/ or competition load can lead to an increased risk of injuries, such as tendinopathy, patella femoral pain, bone stress injuries, ligament strains and muscle sprains (Impellizzeri, Rampinini, & Marcora, 2005). This may be a result of a mismatch between magnitude (duration, frequency, and intensity) of the loading and the recovery time, resulting in micro damage at tissue level (Impellizzeri, Rampinini, & Marcora, 2005).

Tissue fatigue due to repetitive loading will also increase a player's susceptibility to overuse injuries (Soligard, et al., 2016). Fatigue from training and competition leads to reduced muscular force development and contraction velocity (Soligard, et al., 2016). This may cause increased forces on tendons and ligaments and may change kinetics, kinematics, and neural feedback resulting in reduced joint stability. Incorrect loading may increase injury risk by impairing factors such as coordination, decision-making ability and neuromuscular control (Soligard, et al., 2016; Gandevia, 2001). All these factors may contribute to increased risk of overuse injuries, however, TL is the only factor that can be adjusted aiming to prevent of overuse injuries (Soligard, et al., 2016).

Training load is defined as the magnitude of stress imposed on and tolerated by a player (Soligard, et al., 2016). This involves physiological, psychological and mechanical stresses (Soligard, et al., 2016). These stresses stimulate several homeostatic responses, which result in various adaptations of the human body's systems (Virtanen et al., 2010). These adaptations may be beneficial but are not necessarily favorable adaptations (Virtanen et al., 2010; Meeusen et al., 2013; Halson, 2014). These beneficial or undesirable adaptations are results of the external training loads placed on players (Meeusen et al., 2013).

Beneficial adaptations may have a positive effect on the improvement of fitness, reduction of fatigue and consequently improvement of withstanding TL and therefore reducing the risk of overuse injuries (Virtanen et al., 2010). To achieve these beneficial adaptations, training must avoid excessive overloading and inadequate recovery but it must involve overreaching (Meeusen et al., 2013). Overreaching is functional and necessary to improve fitness and performance (Meeusen, et al., 2013). Overreaching is a positive result of TL placed on a player in combination with adequate time to recover (Meeusen, et al., 2013). As TL continually impose stress on players, it may cause constant changes in physical and psychological well-being (Virtanen et al., 2010). These changes will have an effect on acute fatigue and may cause functional and non-functional overreaching (Halson, 2014). When overreaching is functional it will improve fitness and performance (Meeusen et al., 2013; Halson, 2014).

Adequate recovery after a period of intense training may result in positive adaptations and is, therefore, the basis of effective training programs and training sessions (Meeusen et al., 2013; Halson, 2014). However, when the TL increases excessively and the recovery time is insufficient abnormal training responses may occur. This may result in the development of non-functional overreaching (Meeusen et al., 2013; Halson, 2014). Consequently, it will cause short-term maladaptation's, decrements in performance and maybe other negative symptoms (Meeusen et al., 2013; Halson, 2014). Non- functional overreaching may lead to tissue damage, and if the TL is not adjusted, may lead to the overtraining syndrome, also known as overloading (Halson, 2014; Foster, 1998; Meeusen et al., 2013; Kellmann, 2010).

The overtraining syndrome or overloading is defined as placing a player under more load or stress than what the player is prepared for and can withstand and exceeds the player's recovery

capacity (Meeusen, et al., 2013). This is a result of physical trauma whereby the body does not get enough time to repair the damage (Meeusen, et al., 2013). This is most often a result of repetition of a certain movement, for instance, the load placed on the lower extremity during running, change of direction and decelerations and accelerations during football (Meeusen, et al., 2013). This results in micro trauma at tissue level, which may decrease the performance and increase the risk of injury (Meeusen, et al., 2013). When the overtraining syndrome or overloading follows overreaching, the player will experience physiological and psychological signs and symptoms for several weeks to months (Meeusen et al., 2013; Halson, 2014; Foster, 1998). If these signs are not noticed by both coaching and medical staff, the imbalance between high training loads and inappropriate recovery time results in the player being more prone to being injured (Gabbett, et al., 2014). However, when these signs are being noticed and TL is adjusted and adequate recovery time is achieved, the process of damage may be reversed or inhibited and tissue may be able to remodel. Homeostasis may then be restored at a higher level of fitness (Meeusen et al., 2013; Kellmann, 2010). Consequently, the body may be more capable of withstanding the high TL whereby the risk of injuries may be reduced (Meeusen et al., 2013; Kellmann, 2010).

In conclusion, an adequate combination of prescribed TL and appropriate recovery time may result in fitness and performance improvements. It is possible that this may have a positive effect on a player's capacity to withstand high TL and peak demands during match play and potentially reduce the risk of overuse injuries throughout the competitive season (Booth, & Thomason, 1991; Meeusen et al., 2013).

4.1. Internal load

Internal load (IL) is the physiological response of a player to the prescribed load and is measured using variables such as heart rate and perceived exertion. The IL is critical in determining the correct stimulus for the optimum biological adaptation (Wallace et al., 2009; Impellizzeri, Rampinini, & Marcora, 2005; Viru et al., 2010). The session Rating of Perceived Exertion (sRPE) is the most commonly used method to evaluate internal training load (ITL) in football players (Wallace et al., 2009; Brink, et al., 2010). This method requires football players to subjectively rate the intensity of the training sessions and match play by using a Borg 10-point

category ratio scale (Wallace et al., 2009). This method is convenient and the most reliable method in team sports (Wallace, Slattery, & Coutts 2014; Scott et al., 2013; Brink, Nederhof, Visscher, Schmikli, & Lemmink, 2010; Impellizzeri, Rampinini, & Marcora, 2005; Impellizzeri, et al., 2004; Brink, et al., 2010).

Monitoring the ITL requires quantification of the duration and intensity of the physiological stress imposed on the player (Alexiou, & Coutts, 2008). Considering the fact that the purpose of the sRPE subjective measurement is to measure ITL, a combination of an objective measurement to measure ETL will ensure the reliability of both methods and will result in a more effective way to monitor a player's response to TL (Wallace, et al., 2014).

4.2. External load

External load (EL) refers to any external stimulus applied to the player that is measured independently of the internal characteristics (Wallace et al., 2009; Halson, 2014). External load will result in psychological and physiological responses and changes (Wallace et al., 2009; Halson, 2014; Booth, & Thomason, 1991). Measuring EL includes quantifying the training and competition load of a player, such as duration of a training session, the total distance covered (TDC), and number of high- intensity sprints (HIS) (Soligard, et al., 2016; Wallace et al., 2009; Halson, 2014). These outcomes can be measured by Global Positioning Systems (GPS) monitoring.

The internal and external workload together is correlated with the risk of developing overuse injuries (Gabbett, Hulin, Blanch, & Whiteley, 2016). Ideally, a combination of the ITL and external training load (ETL) are used to monitor the response of the prescribed TL of players.

4.3. Mismatch between loads after injury

Inadequate rehabilitation can be explained by the fact that physiotherapist treat players in their early phase of rehabilitation whereas strength and conditioning coaches train players to return to training and play (Gabbett, 2016). In the acute phase after tissue damage, tissue has to repair which requires low loads and less stress. After the first few phases of rehabilitation the player proceeds with the return to training and play phase (Gabbett, 2016). This is the phase of recovery where the player needs to be able to withstand the demands of training and the peak demands of

match play again (Gabbett, 2016). These demands are high and involve strength, agility and endurance. The loads placed on the player during the rehabilitation phase with the physiotherapist has to be increased gradually over time, to ensure that the player is able to withstand these loads (Gabbett, 2016). The same applies for the loads prescribed by strength and conditioning coaches. The phase from physiotherapists prescribed rehabilitation loads may, in some cases, not be in accordance with the training loads placed on the players by strength and conditioning coaches. In other words, physiotherapists aim to treat a player and prescribe the appropriate time to rest and recover (Gabbett, 2016), with their aims being to prevent worsening tissue damage and to encourage the healing process. Strength and conditioning coaches aim to get the players back to the level of fitness as before injury as soon as possible (Gabbett, 2016). However, these loads are usually very high. The difference between the, mostly, low loads prescribed by physiotherapist and the generally very high loads prescribed by strength and conditioning coaches may result in a mismatch between loads which consequently result in spikes in TL (Gabbett, 2016). These spikes in TL may subsequently result in a higher risk of overuse injuries or recurrent injury when players return to play (Gabbett, 2016; Gabbett, & Jenkins, 2011). However, other factors may also affect the risk of overuse injuries.

5. ACUTE AND CHRONIC WORKLOAD

Coaches and strength and conditioning trainers aim to describe ideal training loads resulting in improvement of fitness and performance but not so high as to risk excessive fatigue and high risk of overuse injuries (O'Toole, 1992). Thus, an adequate TL should maximize performance and simultaneously limiting the negative result of too high training loads (Blanch, & Gabbett, 2016). These TL can be described as acute and chronic workloads. The acute workload (AWL) is the load placed on the player during the previous seven days, which represents the 'fatigue' in the acute:chronic workload ratio (Blanch, & Gabbett, 2016). The chronic workload (CWL) represents the load placed on the player during the previous 28 days, which is the weekly average of the AWL (Blanch, & Gabbett, 2016). In addition, the response of a player to a certain TL can be estimated from the difference between the positive (fitness) and negative (fatigue) effects of TL (Blanch, & Gabbett, 2016). Monitoring and understanding a player's fitness and fatigue levels is important in order to understand what the player has done in the previous 4

weeks (chronic) and prepared for in the previous week (acute) (Blanch, & Gabbett, 2016; Soligard, et al., 2016).

The one-week total distance covered and one-week number of high-intensity sprints represents external acute workload (Gabbett, et al., 2016). This is used to classify the relationship between changes in TL and injury risk (Soligard, et al., 2016). A player is considered well-conditioned if the CWL (developed fitness) and the AWL (minimal experienced fatigue) are both progressively increased (Halson, 2014). When AWL exceeds the CWL, fatigue sets in and the player will not improve performance (Soligard, et al., 2016). This pattern most commonly occurs when the player is underprepared and is therefore at a higher risk to develop any injury (Soligard, et al., 2016). When CTL is too little, the player is underprepared for the peak demands during match play and will be at a higher risk to sustain an injury (Soligard, et al., 2016; Abbott, Brickley & Smeeton, 2017). Additionally, the mismatch between AWL and CWL and inadequate recovery may increase the risk of developing an overuse injury (Veugelers, et al., 2016). In other words, underloading or overloading may both result in an unprepared player, that may result in an overuse injury, which is in fact, an error in training prescription, which may be prevented (O'Toole, 1992; Gabbett, 2016; Drew et al., 2016). To determine if the TL placed on the player is underloading or overloading the player, and thus predicting overuse injury risk, the acute:chronic workload ratio is used.

5.1. Acute:chronic workload ratio

Monitoring training and match load is necessary to improve performance and to prevent injuries at the same time (Gabbett, Hulin, Blanch, & Whitely, 2016). The acute: chronic workload ratio (ACWLR) is a method which is able to monitor the internal and external load placed on a player (Gabbett, Hulin, Blanch, & Whitely, 2016). By analyzing the data obtained from the ACWLR, individual fitness may be optimized and the risk of sustaining an injury may consequently be minimized (Gabbett, Hulin, Blanch, & Whitely, 2016). The ACWLR can be used to monitor the players preparedness to the peak demands of match play and may be used to understand and predict a player's relative overuse injury risk. The ACWLR is used to monitor and assess the positive (overreaching and improved fitness) and negative (underloading, overloading, spikes and fatigue) effects of TL (Gabbett, Hulin, Blanch, & Whitely, 2016). The ratio describes the

AWL (previous seven days) and the CWL (previous 28 days, weekly average of the acute workload) aiming to have a high CWL as an optimal result (Gabbett, Hulin, Blanch, & Whitely, 2016; Abbott, Brickley & Smeeton, 2017; Blanch, & Gabbett, 2016).

To calculate ITL, sRPE results are needed for every on-field training session, strength sessions and match played for all players within the team over the full competitive season. Session RPE results are multiplied by the duration of the session in minutes, which results in an outcome in arbitrary units (Gabbett, Hulin, Blanch, & Whitely, 2016).

To calculate ETL, total distance covered (TDC) and high-intensity sprints (HIS), derived from GPS are needed for every on-field training session and match played from all individual players within the team over the full competitive season. Total distance covered and HIS is multiplied by the duration of the session in minutes, which also results in an outcome in arbitrary units (Gabbett, Hulin, Blanch, & Whitely, 2016). This is done per player, per session, per week, per day over the full competitive season.

By dividing the AWL by the CWL, per individual player, the acute:chronic workload ratio (ACWLR) is calculated. Which, ideally, result in an ACWLR ranging between 0.80-1.30 (Gabbett, 2016). This ratio is seen as the most optimal ratio whereby the player has the lowest relative injury risk (Blanch, & Gabbett, 2016). The player has been under loaded if the ACWLR is less than 0.80 and overloaded if greater than 1.30 (Blanch, & Gabbett, 2016). In other words, the player is at a higher risk to sustain an overuse injury in both scenarios, thus an optimal ACWLR should range between 0.80-1.30, in other words; “the sweet spot” (Gabbett, 2016; Blanch, & Gabbett, 2016).

In addition, an ACWLR of 0.50 suggests that the players trained half as much of the workload in the most recent week compared to the average over the past 4 weeks (Blanch, & Gabbett, 2016). An ACWLR of 2.0 suggests that the player performed twice as much of the workload in the current week compared to the average of the previous 4 weeks (Blanch, & Gabbett, 2016). Consequently, spikes in TL occur when the ACWLR is more than 1.3 or if TL differ by more than 20% between and within weeks (Gabbett, et al., 2016; Gabbett, 2014). This is the point

where overuse injury risk starts to increase. In other words, this scenario needs to be prevented (Gabbett, et al., 2016). Previous research concluded that these spikes predict subsequent injury in professional rugby league players and professional Australian football players (Gabbett, et al., 2016). It can be assumed that this is similar for professional football players. However until recently, there has been few studies investigating ACWLR in football.

The study by Hulin et al., (2016) concluded that very-high ACWLR (>2.11) in elite rugby players resulted in a great risk of injury in the current week (16.7% injury risk). In addition, a high absolute CWL ($>16\ 095\text{m}$) combined with a >1.54 ACWLR was associated with the greatest risk of injury (28.6%) (Hulin, et al., 2016).

The ACWLR is often used to assess the progress of an injured player, however, there is little evidence that the ratio can predict safe return to play (RTP) (Blanch, & Gabbett, 2016). This could be a consequence of the reduced CWL during a period of injury. The importance of the amount of training performed in the current week relative to training the player has been prepared for in the previous 4 weeks is crucial (Blanch, & Gabbett, 2016). Thus, the use of the ACWLR is essential to determine and assess the TL placed on the player. Therefore, determining if the TL is overloading or underloading the player to be able to adjust the loads placed on the player in time to prevent overuse injury risk is important (Blanch, & Gabbett, 2016; Abbott, Brickley & Smeeton, 2017).

6. MONITORING LOAD

The monitoring of players is essential to define the relationship between TL and risk factors for overuse injuries (Soligard, et al., 2016). Monitoring should focus on performance as well as sport and non-sports specific stressors. This will improve the understanding of training responses such as fatigue, which will provide guidance on the relationship between a balanced TL and essential recovery time. This will consequently reduce the risk of overuse injuries (Soligard, et al., 2016).

6.1. Session Rating of Perceived Exertion

Session Rating of Perceived Exertion quantifies the ITL of players. This method is developed to eliminate the need to use HR monitors to monitor internal exercise intensity (Scherr, et al., 2013). sRPE is the most commonly used measurement in team sports to measure the ITL during

training and competition (Soligard, et al., 2016). sPRE provides a subjective rating of perceived exertion after a training session or match by a modified Borg 10-point category ratio scale (Scherr, et al., 2013). The measurement quantifies ITL, which involves multiplying the player's sRPE by the duration of the session (Scherr, et al., 2013).

This method is valid and reliable, with individual correlation between sPRE and summated HR zone score ranging between $r = 0.75$ and $r = 0.90$ (Foster, et al., 2001). Research specific to football identified individual correlations between sPRE and HR zones ranging from $r = 0.54$ to 0.78 (Foster, et al., 2001). Additionally, total distance covered during football has demonstrated a strong correlation ($r = 0.80$) with sRPE workload during high-intensity, intermittent team sports training (Blanch, & Gabbett, 2016). Session RPE workload also has a positive correlation with non-contact injury ($r = 0.82$) in rugby league (Blanch, & Gabbett, 2016; Abbott, et al., 2017). Thus, sRPE is a reliable and valid method to quantify training load and can be used for quantitative evaluation of training periodization plans and training sessions (Foster, et al., 2001). However, sRPE has the limitation that it does not differentiate between different training sessions, such as a short-high intensity sessions and, for instance, more prolonged low-intensity sessions (Brink, et al., 2010), which may have varying effects on overuse injury risk (Brink, et al., 2010).

As sRPE does not measure specifics, such as: intensity, movement, and repetitions, more recently, global positioning system (GPS) devices are being used to quantify TL in football (Soligard, et al., 2016). As GPS is very specific to ETL it does not take internal responses of a player into account (Soligard, et al., 2016). This will negatively affect the sensitivity and specificity of the measurement. It can, therefore, be assumed that GPS and sRPE have to be applied in combination to ensure adequate, valid and reliable outcomes (Soligard, et al., 2016).

6.2. Global Positioning System

GPS devices are used to monitor physical activity profiles during training and competition in football players (Murray et al., 2016). GPS can, therefore, be used to quantify the ETL placed on a player, allowing coaches and medical team members to manage TL to prevent the risk of developing overuse injuries (Scott, Scott, & Kelly, 2016).

6.2.1. GPS device operation

The development of the nuclear magnetic resonance method led to the creation of atomic clocks for precise timers (Aughey, 2011). This is the basis of satellite navigation, which allows calculation of the length of time it takes for a radio signal to travel from the satellite to the GPS receiver (Aughey, 2011). The information that the satellites send to the GPS receivers enables the receiver to calculate the distance to the satellite (Scott, Scott, & Kelly, 2016). This is achieved by comparing the time between the satellites' atomic clock and the internal clock of the receiver (Scott, Scott, & Kelly, 2016). If at least 4 satellites are in communication with the GPS receiver, the accurate location of the GPS receiver can be generated with respect to the GPS receivers' latitude, longitude, and altitude (Scott, Scott, & Kelly, 2016; Aughey, 2011). When the position of the GPS receiver is known, the movement over a specific area can be used to calculate the velocity of the movement of the GPS receiver (Aughey, 2011). The GPS devices used in sport calculate speed by using Doppler shift (Aughey, 2011). Doppler shift calculates the change in frequency or wavelength of a wave from the GPS receiver to the satellite (Aughey, 2011). This is achieved by examining the frequency of the satellite signal (Scott, Scott, & Kelly, 2016).

GPS devices are classified by the rate at which they sample per second e.g. 1 Hertz, 5 Hertz, 10 Hertz and 15 Hertz (Cummins, Orr, O'Connor, & West, 2013). Hertz is defined as the number of cycles per second to define electrical signals or frequencies (Cummins, Orr, O'Connor, & West, 2013). One Hz samples one cycle per second, 10 Hz samples 10 cycles per second (Jennings et al., 2010). As 10 Hz devices sample more frequently compared to 5 Hz devices, 10 Hz GPS devices are considered more valid and reliable in team sports such as football (Scott, Scott, & Kelly, 2016). Fifteen Hertz GPS devices have no additional benefits compared to the 10 Hz GPS devices (Scott, Scott, & Kelly, 2016).

6.2.2. Validity of 10 Hz GPS devices

Ten Hertz GPS devices have adequate validity and reliability when measuring velocity, distance, acceleration, and players TL (Boyd et al., 2011; Varley et al., 2012). The higher the sample rate, and the longer the duration of a measured task, the more valid GPS measured distance becomes (Aughey 2011). Current research concluded that the increase in sampling rate to 10 Hz for GPS

devices has superior validity for measuring distance compared to 1Hz and 5 Hz devices (Aughey, 2010).

Ten Hertz GPS devices are able to quantify short to moderate distances (15-30 meters) with higher accuracy than the 1 and 5 Hz devices (Scott, Scott, & Kelly, 2016). The validity of the 10 Hz GPS devices is considered moderate to good while measuring instantaneous velocities during constant velocity running and running involving accelerations (Castellano, et al., 2011). The validity of the instantaneous velocity improves as the initial velocity of the running increases. However, when decelerations occur the validity of the 10 Hz GPS units become poor (Castellano, et al., 2011). In addition, 10 Hz GPS devices may overestimate players' peak speed during matches. This may be a result of poor estimations regarding instantaneous velocity in high accelerations during team sports matches (Scott, Scott, Kelly, 2016). Nonetheless, the overall validity of 10 Hz GPS devices is better than the validity of the 1 and 5 Hz GPS devices (Boyd et al., 2011; Varley et al., 2012).

6.2.3. Reliability and accuracy of 10 Hz GPS devices

The reliability of GPS devices is influenced by various factors, such as velocity, sample rate, duration and type of the task (Aughey, 2011). High velocities of the movement, changes of direction, repetitive actions, and football specific tasks may lower the reliability of GPS devices (Duffield, et al., 2010). Environmental objects, such as stadiums, can obstruct satellite signals, which may result in measurement errors (Scott, Scott, & Kelly, 2016). The number of satellites communication with the GPS receiver plays an important role in determining the accuracy (Scott, Scott, & Kelly, 2016).

The intra unit reliability of the 10 Hz GPS unit is good (CV 5%) during 15-30-meter distance sprints (Castellano, et al., 2011). The reliability increases when the distance of the sprints increases (Castellano, et al., 2011). Ten Hertz GPS units inter unit reliability is good for the total distance covered (Castellano, et al., 2011). In addition, typical error of measurement (TEM) is 1.3% with intra-class correlations (ICC) of 0.51% whereby high-speed running distance has TEM 4.8% and ICC 0.88 (Castellano, et al., 2011). The study by Varley, Fairweather, & Aughey, (2012) concluded that 10 Hz GPS devices have a moderate to good inter-unit reliability while measuring instantaneous velocity during running, running involving decelerations (6.0%

CV), constant-velocity running (2.0-5.3% CV) and running involving accelerations (1.9-4.3% CV).

Additionally, the study by Jennings et al., (2010) investigated the variability between two GPS units on the same hockey player for total distance and high-intensity sprints and concluded that the collected data was similar with approximately 10% difference. The reliability of these two GPS units is similar to the between-players standard deviation of Australian football players for high-intensity sprints but smaller than high-intensity sprints reported in professional football players (Jennings et al., 2010).

Ten Hertz GPS devices validly measure running distance in football during varying speeds (Scott, Scott, & Kelly, 2016). The study by Rampinini et al., (2015) concluded that 10 Hz GPS devices have good accuracy during high-intensity sprints and total distance measurements over 70 meters (1.9% CV). These devices produce acceptable measurement accuracy for short distance sprints, but the mean standard error of measurement (SEM) is still greater than 10% during sprints shorter than 10 meters (Scott, Scott, & Kelly, 2016; Castellano, et al., 2011).

Understanding the variations in activity profile during training and matches allows modification of the training program so that players are able to adapt to the required match load (Aughey, 2011). It can be assumed that it may be beneficial to compare the data collected during training and matches and therefore analyzing the demands placed on the players during training and match play. Therefore, ensuring that the demands of training equal the demands placed on the players during match play (Aughey, 2011).

In conclusion, 10 Hz GPS devices are valid, reliable and accurate to measure total distance and to detect different high-intensity sprints across a match, and between matches (Aughey, 2011; Scott, Scott, & Kelly, 2016). Furthermore, 10 Hz GPS devices are able to measure activity profiles of football players during training (Aughey, 2011). It is therefore suggested to use 10 Hz GPS devices in team sports such as football (Scott, Scott, & Kelly, 2016). Given the fact that the 10 Hz GPS devices are the most reliable, this study will use 10 Hz VX-Sport GPS devices.

7. CONCLUSION

Training and match-play time is necessary to improve performance to ensure the player reaches the peak demands of professional football. Adequate prescription of TL is necessary to withstand peak demands during match play, to improve fitness and reduce the negative effects of excessively high TL. However, players are at risk of overuse injuries that may be preventable through monitoring these loads. Monitoring and the assessment of ITL and ETL may reduce the number of overuse injuries in professional football players. Adequate TL should focus on the prevention of spikes and aim to prepare football players for the peak demands of match play. By calculating and monitoring the acute and chronic workload ratio, the TL can be adjusted which may prevent overuse injuries and ideally resulting in ACWLR varying between 0.8-1.30. Further research is needed to determine how we can predict the risk of overuse injuries and how to prescribe an optimal TL per players and thereby taking into account the peak demands per playing position.

8. INTERNAL AND EXTERNAL LOAD MEASURES AS PREDICTORS OF OVERUSE INJURY RISK IN PROFESSIONAL FOOTBALL PLAYERS

8.1 Methodology

8.1.1 Aim

The aim of this study was to determine the effect of the total GPS distance covered, the number of GPS measured high-intensity sprints and sRPE load and the effect of these load metrics on the risk of developing an overuse injury in professional football players.

8.1.2 Objectives

- 1) To determine the relationship between total GPS distance (m) covered, ACWLR and overuse injuries in a full competitive season.
- 2) To determine the relationship between GPS measured high-intensity sprints, ACWLR and overuse injuries in a full competitive season.
- 3) To determine the relationship between session rating of perceived exertion, ACWLR and overuse injuries in a full competitive season.

- 4) To determine the overuse injury risk per playing position (defenders, midfielders and attackers)
- 5) To determine the patterns of injury during a full competitive season.
- 6) To determine the effect of the internal load (sRPE) and external load (GPS) in a congestion week compared to a normal week on overuse injury risk.

8.1.3 Study design

Retrospective cohort study design.

8.1.4 Participants

Thirty-two professional male football players in the first team of a professional football team in South Africa.

8.1.5 Inclusion criteria

Healthy professional male football players in the first team of a professional football team in South Africa.

8.1.6 Exclusion criteria

- Goalkeepers
- Traumatic and contact injuries
- Upper extremity, abdominal, and head injuries
- Medical attention injuries without time-loss

8.1.7 Sample size

Data from previous studies that investigated the influence of internal or external load on injury risk were used to ensure that the sample size would provide sufficient statistical power.

Previous studies, for example Hulin et al., (2014), Bowen et al., (2016), Hulin et al., (2016), Murray et al., (2014) and the study of Bengtsson et al., (2013) collected data from 26-32 football and rugby players.

8.2. MEASUREMENT INSTRUMENTS

8.2.1 Session Rating of Perceived Exertion

Session Rating of Perceived Exertion (sRPE) is the most commonly used measurement in team sports, including football, to measure internal workload during training and competition (Brink, et al., 2010). sRPE provides a subjective rating of perceived exertion after a training session by a Borg 10-point category ratio scale (see Appendix III). This method is developed to eliminate the need to use HR monitors to assess internal exercise intensity.

The measurement quantifies internal training load, which involves multiplying the player's sRPE by the duration of the session. Additionally, total distance covered has demonstrated a strong correlation ($r = 0.80$) with sRPE workload during high-intensity, intermittent team sport training (Blanch, & Gabbett, 2016). Session-RPE workload also has a positive correlation with non-contact injury ($r = 0.82$) in rugby league (Blanch, & Gabbett, 2016). sRPE is a reliable and valid method to quantify training load and can be used for quantitative evaluation of training periodization plans (Foster, et al., 2001).

The sRPE was recorded within 10 minutes following the completion of the training session. The players were familiar with the Borg category ratio (CR10) scale as they have been using this subjective method for a few seasons. The response was recorded on a table for recording values for each player throughout the entire season. sRPE is subsequently calculated from the overall training time multiplied by the specific sRPE value provided for each player.

8.2.2 Global Positioning System

Global positioning system (GPS) is used to monitor physical activity profiles during training and competition in football players (Murray et al., 2016). GPS can therefore be used to quantify the external load, consisting of the total distance covered and the number of high-intensity sprints ($>20\text{km/h}$, 15-30 meter) (Hulin, Gabbett, Lawson, & Sampson, 2016). GPS may therefore assist coaches with the management of training loads, potentially identifying inappropriate training loads which could otherwise result in overreaching, overtraining or overuse injuries (Scott, Scott, & Kelly, 2016).

Ten Hertz GPS devices, such as the VX- sport, are the most valid and reliable in team sport (Scott, Scott, & Kelly, 2016). Ten Hertz GPS devices have adequate validity and reliability when measuring velocity, distance, acceleration, and player load (Boyd et al., 2011; Varley et al., 2012). Whereby the devices are able to quantify short to moderate distances (15-30 meters) of high-intensity sprints, with higher accuracy than the 1 and 5 Hz devices (Scott, Scott, & Kelly, 2016). The validity of the 10 Hz GPS devices is moderate to good while measuring instantaneous velocities during constant velocity running and running involving accelerations (Castellano, et al., 2011). The validity of the instantaneous velocity improved as the initial velocity of the running increased. However, when decelerations occur during instantaneous velocities, the validity of the 10 Hz GPS units become poor (Castellano, et al., 2011). The reliability of GPS devices is influenced by various factors, such as: velocity, sample rate, duration and type of the task (Aughey, 2011). The study of Rampinini et al., (2015) and Aughey, (2011) concluded that 10 Hz GPS devices have good accuracy for high-intensity sprints and the total distance covered. In conclusion, in spite of some limitations as mentioned above, 10 Hz GPS devices are the most reliable and valid method to measure external load in team sports such as football.

The players wore their GPS devices during all field based training sessions. The GPS units (10 Hertz VX system) are placed in a vest located posteriorly between the scapulae. All players wore the same 10 Hertz VX-sport GPS device. This device is valid and reliable for measuring total distance covered and high-intensity sprints (Scott, Scott, & Kelly, 2016). The strength- and conditioning coach collected the GPS units after every training session and the data was then downloaded using the specialized analysis software. The system will automatically generate a weekly report for each player, which provides total distance covered (TDC) and the number of high-intensity sprints (HIS).

9. PROCEDURES

Data was collected from professional football players in the Premier Soccer League (PSL) in South Africa. Thirty-two male professional football players [mean \pm standard deviate (SD): age 24.3 ± 4.07 year; height 173.4 ± 6.02 cm; body mass 74.3 ± 6.68 kg], who all played at least half of the 2016/2017 competitive PSL season participated in this study. The players were recruited through direct communications with the club. This recruitment procedure ensured uniform

distribution of relevant study information and procedures. All players provided written informed consent in accordance with the Declaration of Helsinki prior to the study. The study was approved by the Faculty of health Sciences Human Research Ethics Committee at the University of Cape Town, South Africa.

The duration of the research study covered one full competitive PSL season, including pre-season and consisting of all league and cup matches. Pre-season, and therefore data collection started on the 1st of July 2016. The competitive season started officially on the 1st of August 2016 and the last match was played the 27th of May 2017. Data has been collected from 1 July 2016 to 27 May 2017.

9.1 Competitive season

The players trained on a full-time basis and played competitive fixtures during the competitive season from August 2016 until May 2017. The team played 30 league games over 30 weeks. Competitive fixtures were normally played on Saturday or on Wednesday, and occasionally on Tuesday, Friday or Sunday. On-field training sessions and gym sessions were on Mondays, Tuesdays, Thursdays, and Fridays. The players had a rest day on either Sundays or Wednesday and a light technical match preparation session the day before a match.

They trained five to six times per week and the duration of an on-field training session was generally 60-120 minutes and 60 minutes for gym sessions. Training consists of physical conditioning and technical training including; sprint training, speed endurance training, high intensity aerobic training and strength training. The structure of an in- season on-field training session consists of a general and specific warm-up, consisting of; jogging, static/dynamic stretches, shuttle runs, and dribbling drills followed by longer passing and agility drills. The technical part of the training session consists of small-sided games and full-field match play. All on-field training sessions end with static/dynamic stretching. At least one member of the medical team attended the training sessions.

9.2 Data collection

Internal activity profiles of 32 players were monitored during either the full competitive PSL season (47 weeks) or half of the competitive PSL season (20-26 weeks). However, only 22 players internal and external activity profiles were analyzed for this study. Some players signed a contract with the club at the beginning of the season but transferred to another PSL club halfway the season. Other players only signed a contract after the Christmas break. Data collection only started when the player was officially signed to play for the club.

The analysis included all on-field training sessions and matches throughout the 2016/2017 competitive season. Rehabilitation sessions and return to play sessions were not included in the analysis of this research as this would have adversely affected the outcome of the TL data used to assess overuse injury risk.

External training load was monitored during on-field training sessions and matches using 10 Hz VX-Sport GPS devices. All players wore the same 10 Hertz VX-sport GPS device throughout the season, to ensure the reliability of the device. VX-sport is valid and reliable for measuring total distance covered and the number of high-intensity sprints (Scott, Scott, & Kelly, 2016). The GPS devices were worn in a vest, fitting the unit in a pocket between the scapulae. Total distance (m) covered and the number of high-intensity sprints during all on-field training sessions and matches were collected and used to analyze the ETL placed on the players. The total distance covered includes all meters covered in; walking, jogging, fast running and high-intensity sprints (Bowen, et al., 2016). High-intensity sprints are defined as sprints exceeding 24km/h for 15-30 meter (Hulin, Gabbett, Lawson, Caputi, & Sampson 2016).

The strength- and conditioning coach collected the GPS units after every session and the data was then downloaded using the specialized analysis software. The system generated an automated weekly report for each player, which provided total distance covered and the number of high-intensity sprints in arbitrary units.

Due to logistic problems, the GPS units were not worn during match preparation sessions the day before a match. However, data was available from three match preparations sessions. These three sessions were calculated to an average and these averages were used for all players for the

missing match preparation sessions. Therefore, the estimated average was calculated and added for all individual players which resulted in a 20% estimation of the external training load during the full competitive season for each player.

The internal workload was quantified using session Rating of Perceived Exertion (sRPE) (Foster, et al., 2001). Players were asked to provide a subjective rating of perceived exertion using a Borg 10-point category ratio scale (Appendix IV) as an estimate of training intensity. A subjective rating of 2 corresponds to an “easy”, 5 as “hard” and 9 very, very hard (Gabbett, & Domrow, 2007). Intensity estimates were recorded within 30 minutes after every on-field training session, strength training session and match played. Training load was calculated by multiplying the training sessions intensity, thus, sRPE results, by the session duration and was reported in arbitrary units, which provides an estimate of ITL (Gabbett, & Domrow, 2007; Foster, et al., 2001). The internal acute TL is calculated by multiplying the sRPE by session duration (min) and the external acute TL is calculated by multiplying the arbitrary units by session duration. Therefore, the acute chronic workload (ACWL) is calculated per day to a weekly average. The weekly average represents the ACWL over the full competitive season over 47 weeks or for half a season respectively.

9.3 DATA ANALYSIS

9.3.1 Training load

Data was categorized into weekly blocks from Monday to Sunday. Variables selected for the analysis were total training and match duration (min), total distance (m), and number of high-intensity sprints for ETL. sRPE was analyzed for ITL. The weekly load was quantified by combining external load (GPS) variable with internal responses (sRPE). The one-week total for each variable represented the ATL (7 days). The CTL was calculated as the four-week rolling average of each variable. Internal and external TL values were converted into ACWLR for the previous week and the rolling average of the prior 28 days (Hulin et al., 2015). The ACWLR is calculated by dividing acute TL by chronic TL (Lazarus, et al., 2017). The resulting measure was expressed in arbitrary units. These variables were analyzed separately and in relation to each other by using Chi-square analysis.

9.3.2 Descriptive injury data

The data of thirty-two players was used for the descriptive injury study. Data from players that did not sustain an overuse injury during the 2016-2017 full competitive season were not included in the analysis of the study.

Injuries were diagnosed and recorded by the team's physiotherapist and team's physician in a specific injury spreadsheet. The type of information recorded, included; the date of injury, date of assessment, the date of return to play (RTP), injured area, type of injury, match vs training, and recurrence. A recurrent injury was defined as an injury affecting the same structure, at the same site and of the same type as the previous injury, which occurred after return to play (Fuller, et al., 2006), during the full 2016/ 2017 competitive season. Sustained injuries were defined as per training or match play injury and were recorded as time- loss injuries if the player was not able to return to play within 24 hours. Medical attention injuries whereby the player is able to participate in full training the next day (within 24 hours) are not included in this research. Injuries unrelated to football, contact injuries and illness were not included in this research. Injuries affecting the upper extremity, abdominal, head or involved a goal keeper were also not included in the research. Thus, the study only included time-loss overuse injuries affecting the lower extremity. An overuse injury is defined as an injury occurring slowly and progressively over time and are caused by repetitive motion or micro trauma and/ or accumulative movements without an identifiable responsible event (O'Kane, et al., 2017; Sobrino & Guillen, 2017). Overuse injuries are different to acute contact injuries caused by an acute moment or identifiable trauma. Inadequate prescribed TL, repetitive movements, deficient technical execution performed for long periods (full competitive season) in combination with inadequate and insufficient recovery (O'Kane, et al., 2017; Sobrino & Guillen, 2017). In addition, an injury was seen as an overuse injury and included in the analysis of the study when an either very low (<0.8) or very high (>1.30) ITL or ETL ACWLR or spikes in ACWLR were recorded, resulting in an injury.

Time-loss overuse injuries are categorized according to the site of injury and include; hip/ groin/ adductors, thigh, quadriceps, hamstrings, knee, calf, and ankle/ foot injuries per 1 000 hours. Groin injuries are classified by the Doha agreement (2015), and include all adductor, iliopsoas,

inguinal, hip and pubic related groin pain.

Overuse injury severity was classified as per total days out of training and competition (Fuller, et al., 2006). A player was seen as “injured” until he was able to return to full participation in training and competition (Fuller, et al., 2006). A minimal injury is defined as >24hours – 3 days of football activity missed, mild (4–7 days), moderate (1–4 weeks) or severe (4+ weeks) (Bowen, et al., 2016). The risks of these injuries are calculated as the number of injuries sustained relative to the exposure of each workload classification.

9.3.3 Training and match injury exposure and incidence

Injury incidence is calculated by dividing the total number of overuse injuries by the overall injury exposure, and expressed as rates per 1 000 hours (Bowen, et al., 2016).

Match injury exposure is calculated by multiplying the number of players by the session duration of match play and the number of matches played (Bowen, et al., 2016). Total number of injuries sustained during match play were divided by the exposure hours and described as injuries per 1 000 match playing hours (Bowen, et al., 2016).

On-field training overuse injury exposure was calculated by multiplying the number of players by the average duration of the on-field training sessions and the number of on-field training sessions during the full competitive season (Bowen, et al., 2016). The team also performed, on average, two strength training sessions per week of 60 minutes duration each and these were included in the training exposure rates. The total number of injuries sustained during training sessions was therefore divided by the total exposure hours of on-field training and strength training and described as injuries per 1 000 training hours (Bowen, et al., 2016).

9.3.4 ACWLR and injury risk

Data collected for GPS total distance (external load), high intensity sprints (external load) and sRPE (internal load) were compared for the 3 weeks prior to the injury to assess for statistically significant differences in the rates of injury for each ACWLR zone compared to expected rates (average ratio of injured to uninjured player weeks). The ACWLR and injury risk was calculated by comparing actual injury rates to the expected occurrence (season average) against ACWLR

for each variable (sRPE, TDC, HIS) for the three weeks prior to the onset of the injury (Gabbett, & Domrow, 2007).

The null-hypothesis testing was conducted using Chi-square analysis including: injury/ no injury as the dependent variable. ACWLR and injury risk was assessed using Gabbett's "sweet spot" of 0.8-1.3 and Malone's zone of 1.0-1.25 (Gabbett, 2006; & Gabbett, 2007; Gabbett, Malone et al., 2017). The chi-squared (w^2) test was used to determine whether the actual occurrence of injury was significantly different from the expected occurrence of injury.

9.3.5 Qualitative analysis

The external TL data for each player was plotted over time and marked for overuse injuries for each individual player. The data was analysed subjectively to determine if there were patterns between increased or decreased ACWLR of TDC and HIS and injury risk per individual player. In addition, large week-to-week differences of more than 20% were analyzed to see if this resulted in an increased injury risk. Additionally, differences of more than 20% between ACWLR of TDC and HIS were analyzed to determine if this was related to an increased injury risk.

9.4. ETHICAL CONSIDERATIONS

The study was approved by the Human Research Ethics Committee of the Faculty of Health Sciences, University of Cape Town (HREC-REF: 809/2017).

All participants completed the informed consent form for the football database (Appendix I) prior to their inclusion in the research database (R026/2016). This study did not require any additional ethical approval, as the data collected formed part of a the football database already approved by the HREC. The analysis of the data and publication of this research is in line with the existing informed consent for the registered database. The study was performed in accordance with the principles of the Declaration of Helsinki (Seoul version, 2013).

Risk and benefits to the participants were explained in the information sheet relating to the research database wherein the right to withdraw from the research study at any time is described. Paper records are kept in a secure location and only accessible to medical staff. Computer-based

records are only available to medical staff involved in the study through the use of access passwords. The identity of the players has not been disclosed in any report or publications and the collected data has been kept confidential.

9.5 Risk to the participants

There were no risks or adverse effects to the players associated with the research study, as this research study was an observation. The study did not affect any activities that the players perform with the club on a daily basis.

9.6 Benefits to the participants

Players and staff may gain a better understanding of risk factors of overuse injuries and how internal and external training load may affect the risk of developing an overuse injury. The results of this study may therefore provide guidelines for coaching staff and medical team regarding training load to potentially help to prevent overuse injuries.

9.7 Significance of the study

This study monitored the internal and external workload and overuse injury risk of South African Premier League football players during a full competitive season (30 weeks).

The study will provide objective and subjective outcomes, which will provide a better understanding for the medical team regarding overuse injury incidence and risk factors associated with internal and external load. Therefore, it will assist with intervention and rehabilitation programs to prevent such injuries.

The information gained from this research study will increase the knowledge of internal and external load and TL and overuse injury risk in South African football.

10. RESULTS

10.1 Descriptive injury results

Over the full 2016/ 2017 competitive season a total of 69 injuries were sustained in a squad of 32 players. Seventeen of these injuries were either acute contact injuries, injuries affecting the upper

limb, head or abdominals or involved a goalkeeper. These injuries were not included in the analysis of this research.

A total of 52 non-contact overuse injuries were recorded and included in the analysis for the descriptive injury analysis. Twenty-five players out of a squad of 32 players sustained an overuse injury during 31 matches in a full competitive season over a nine-month period. Twenty-two players were included for the analysis of external training load (total distance covered and number of high intensity sprints), internal training load (sRPE) and overuse injuries. Therefore, 11 injuries out of 52 overuse injuries were excluded for the analysis for external training load and injuries. Descriptive statistics for all absolute overuse injuries are summarized in **Table 1**.

Injury classification	Number	%
Overall injuries	69	
Acute/ contact injuries	17	
Overuse injuries	52	
Affected body part		
Hamstring	25	48.1%
Groin	12	23.1%
Adductor related groin pain	6	50%
Pubic related groin pain	4	33.3%
Inguinal related groin pain	2	16.7%
Quadriceps	6	11.5%
Others (hip flexor and glut. med.)	3	5.8%
Hip	1	1.9%
Lower leg	3	5.8%
Ankle	1	1.9%
Knee	1	1.9%
Severity		
Minimal	5	9.6%
Mild	13	25%
Moderate	30	57.7%
Severe	4	7.7%
Activity performed		
Training	25	48.1%
Match	27	51.9%

Position played		
Defenders	17	32.7%
Midfielders	26	50%
Attackers	9	17.3%

Table 1 Total overuse injuries 2016/17 full competitive season

Muscles were the mostly frequently injured structure (85%). Hamstring strains accounted for 48.1% of the total overuse injuries sustained in the full competitive season. Groin injuries including adductor, inguinal and pubic related groin pain accounted for 23.1% of all injuries sustained. Quadriceps injuries were the third most common site of injury (11.5%). Others, defined as injuries affecting hip flexors and gluteus medius accounted for 5.8% of all injuries. Time-loss injury affecting the hip joint, specifically a hip labral injury only occurred once (1.9%). Lower leg injuries, including gastrocnemius and peroneus longus injuries occurred three times (5.8%). Non-contact overuse injuries affecting both the ankle and the knee (3.8%) only occurred once (**figure 1**).

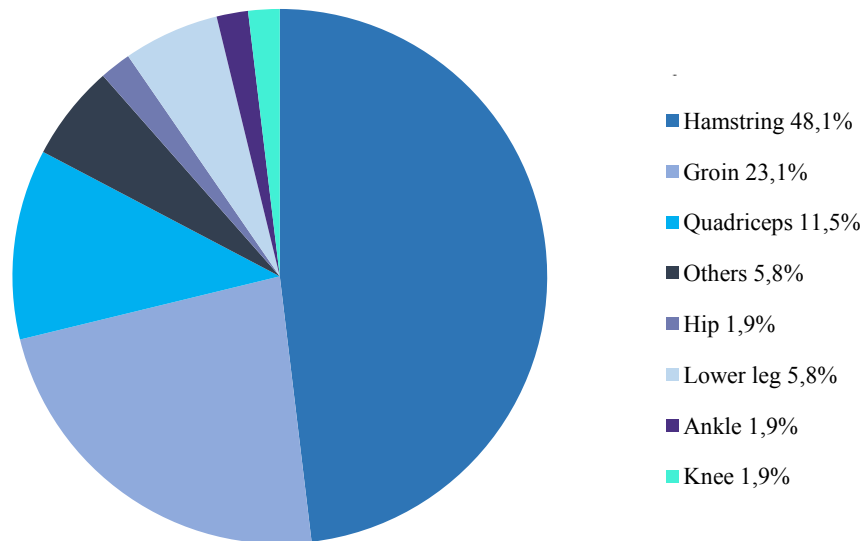


Figure 1 Injured body part

Figure 2 displays the severity of time-loss injuries. Taking injury severity into account, most injuries were moderate injuries (57.7%) and mild injuries (25%). Only 9.6% of all overuse injuries were minimal injuries and 7.7% of all overuse injuries were classified as severe. Hamstring, groin and quadriceps were most frequently (46.2%) classified as moderate injuries,

with a maximum of eight days out of training and match play. A total of five, mostly groin injuries, were classified as severe injuries as these players only returned to play after more than 28 days of treatment and rehabilitation. Fourteen injuries were classified as mild injuries and affected mostly hamstring and groin (21.2%).

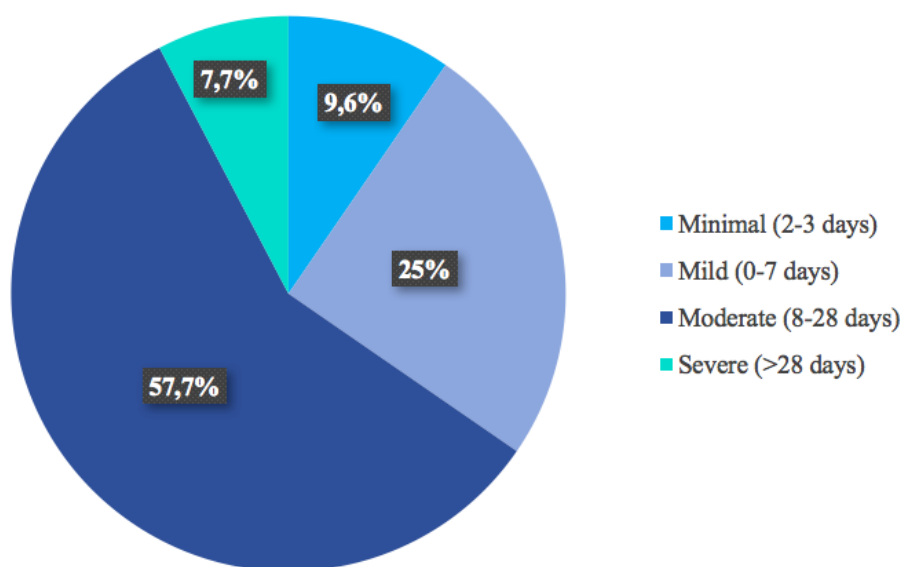


Figure 2 Time-loss by severity

Midfielders were most likely to sustain an injury (50%), followed by defenders (32.7%) and attackers (17.3%) (**figure 3a**). However, this differed to injury risk when expressed as injuries per 1 000 exposure hours (see 10.2.2 below). Per 1 000 hours of match play, defenders sustained 23.7 injuries (44%). Attackers sustained 17.2 injuries per 1 000 hours of match play (32%). Midfielders sustained the least injuries (10.7) per 1 000 hours of match play (24%) (**figure 3b**). During training, attackers were most likely to get injured (39%) and sustained 2.12 injuries per 1 000 hours. Defenders sustained 1.7 injuries per 1 000 hours (31%) and midfielders only sustained 1.6 injuries per 1 000 hours (30%) (**figure 3c**).

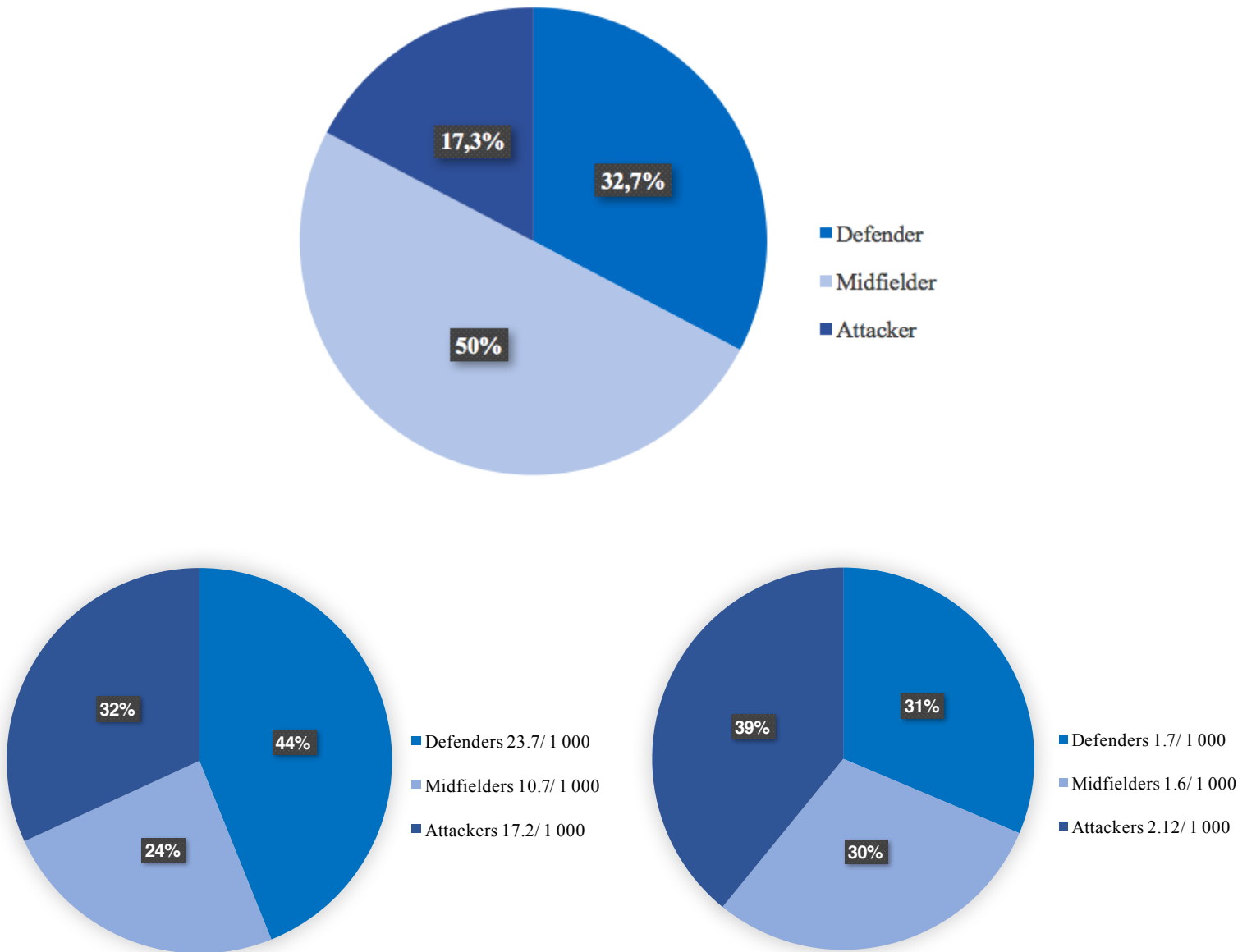


Figure 3a Absolute overuse injuries per playing position, **3b** Relative overuse injuries per 1 000 hours of match play, **3c** Relative overuse injuries per 1 000 hours of training

Midfielders experienced the highest risk of absolute injuries affecting the hamstring, quadriceps, hip flexors and knee. Defenders sustained mostly hamstring and groin injuries. Attackers were least often injured, and most often sustained injuries affecting the hamstring, groin and lower leg (**figure 4**).

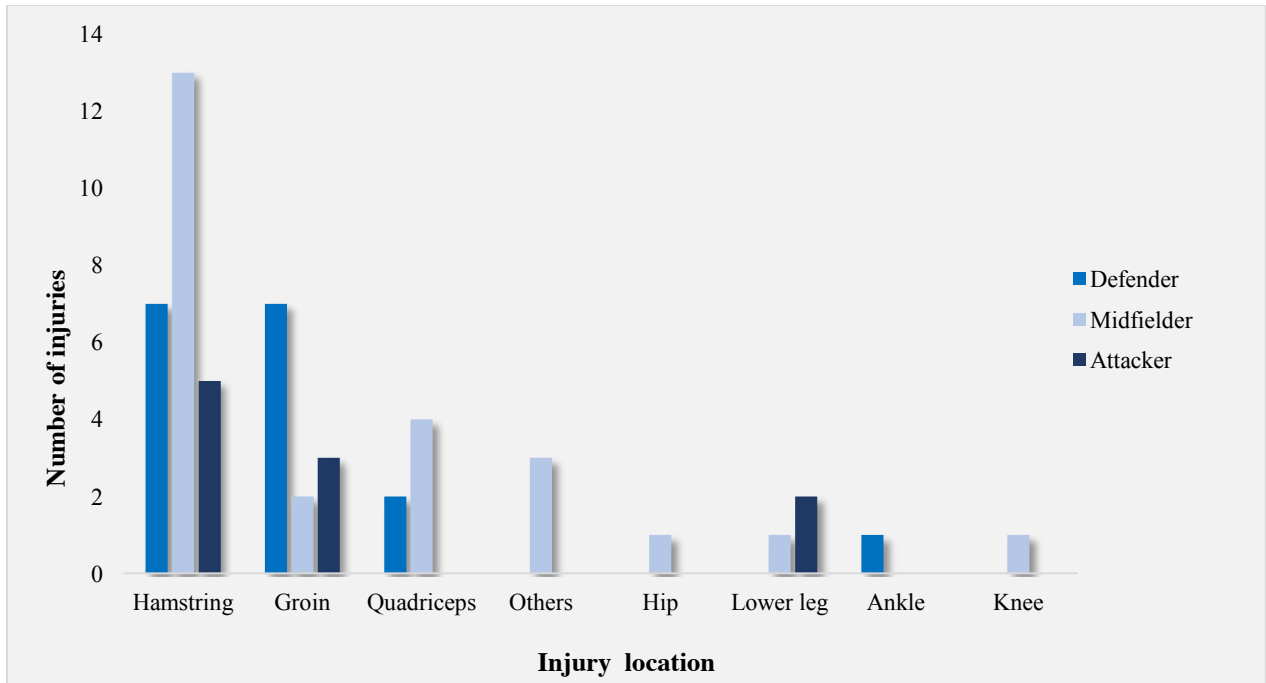


Figure 4 Overuse injuries per playing position

Twenty-five players were unable to train or compete for a total of 221 days after suffering a hamstring injury, with on average of 9.2 days of return to play (**table 2**). Groin injuries resulted in the greatest number of days missed (385 days), with on average 29.8 days before return to play. Injuries affecting the quadriceps resulted in a total of 42 days out of training and competition. Return to play on was average accomplished within 7 days.

Other injuries, such as hip flexor injuries and gluteus medius injuries resulted in a total of 53 days out of training and competition with on average 17.7 days until return to play. Injuries affecting the lower leg required, on average, 14.7 days of rehabilitation before returning to play, and resulted in a total of 44 days out of training and competition for three players who suffered a lower leg injury. Overuse injuries affecting the hip, ankle, and knee only occurred once and resulted together in eight days out of training and competition and return to play respectively.

Injured body part	Total days out	Average days RTP	Minimal days	Maximal days out	Recurrent injury
Hamstring	221	9,2	3	23	2
Groin	358	29.8	3	121	2
Quadriceps	42	7	2	10	2
Others	53	17.7	6	34	0
Hip	11	11	11	11	0
Lower leg	44	14.7	10	20	0
Ankle	7	7	7	7	0
Knee	6	6	6	6	0

Table 2 Total days out of training and competition and RTP

Out of 52 non-contact overuse injuries, 27 injuries (51.9%) were sustained during match play and 25 injuries occurred during training (48.1%).

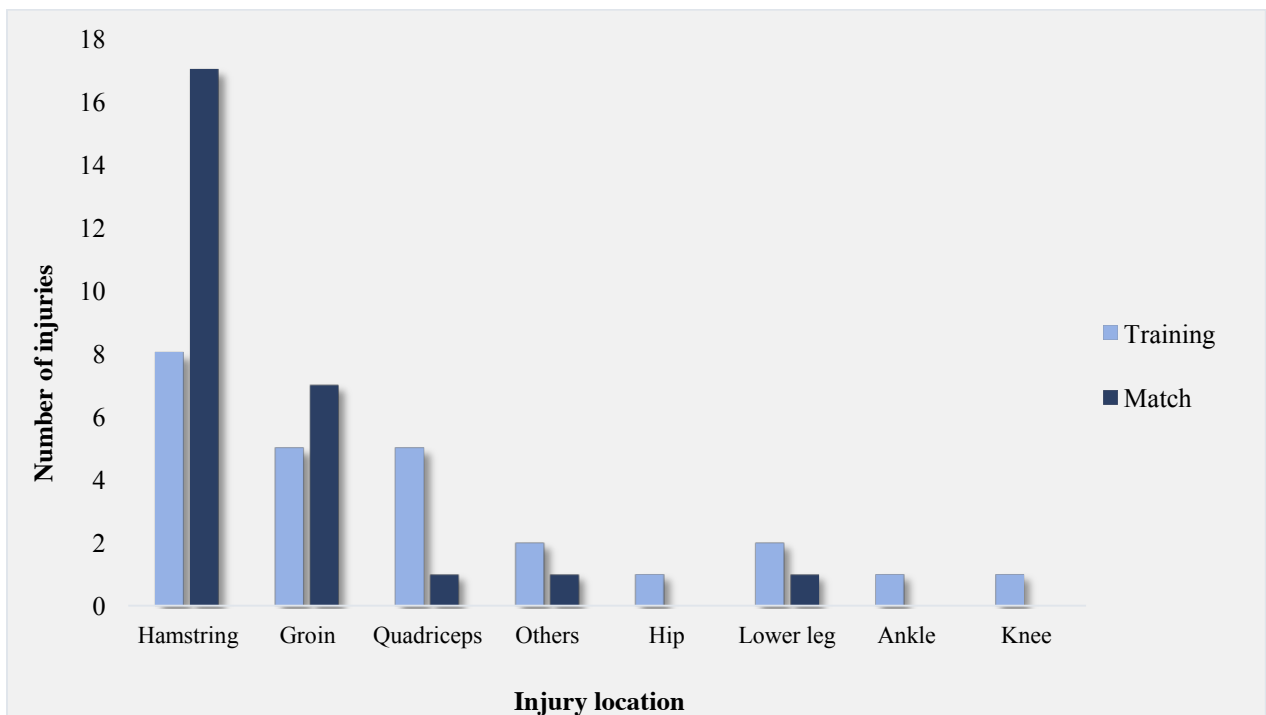


Figure 5 Overuse injuries sustained during training or match per body part

Hamstring and quadriceps injuries occurred consistently throughout the full season (**figure 6**). Groin injuries were mostly sustained in the mid-season rather than pre-season and late season. Lower leg injuries occurred either in pre-season or in the end of the season.

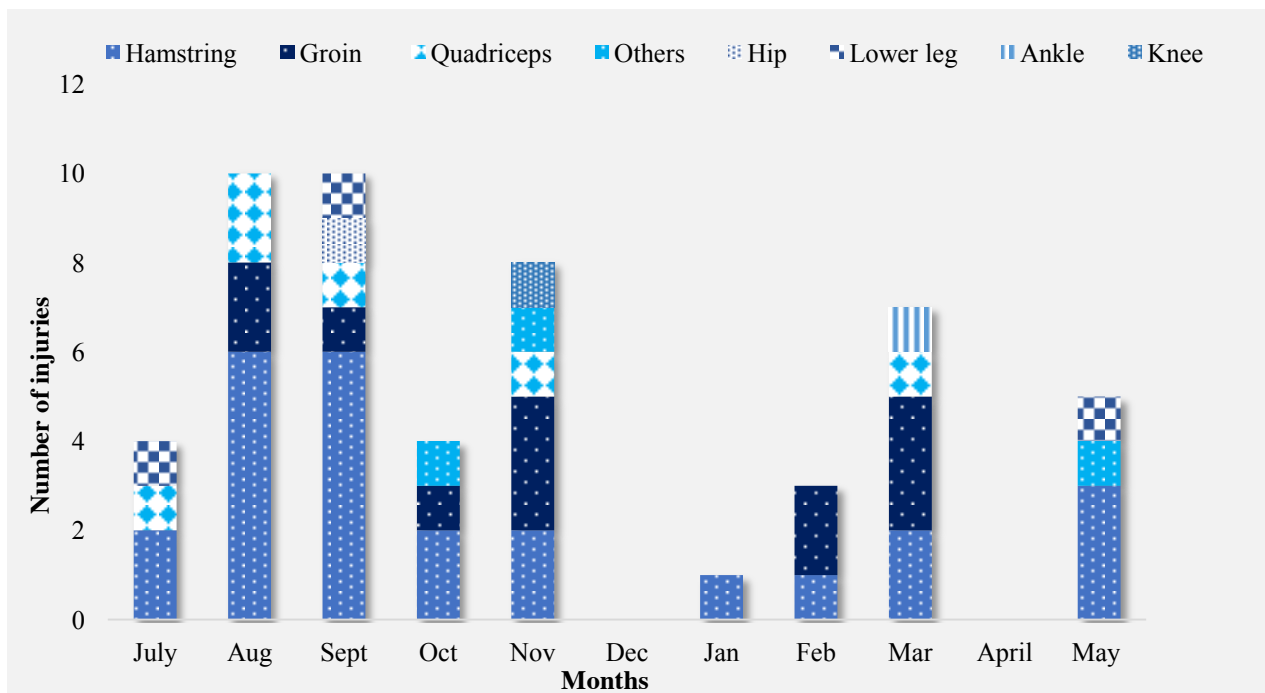


Figure 6 Overuse injuries per month

Throughout the full competitive season, 31 matches were played. On average, three matches were played per month. With a total of eight congestion weeks, over six months (**figure 7 a, b**).

There was no clear relationship between congestion weeks and overuse injury risk in training or match play. Only one friendly match was played in July while August included one official match and five friendly matches, resulting in eight injuries of which only two were sustained during training. Three matches were played in September resulting in nine overuse injuries sustained during either match play or training. Both October and November included one congestion week, resulting together in nine match injuries and three training injuries respectively. No injuries were sustained in December, even though there were three matches played within seven days.

Only one match overuse injury was sustained in February, even though there was one congestion week. In contrast, two matches were played in March without congestion resulting in four overuse injuries sustained during these matches. Even though April included the matches of the full competitive PSL season, no overuse injuries were sustained. May included one congestion

week, wherein four matches were played resulting in two match overuse injuries and three training injuries (**figure 7 a, b**).

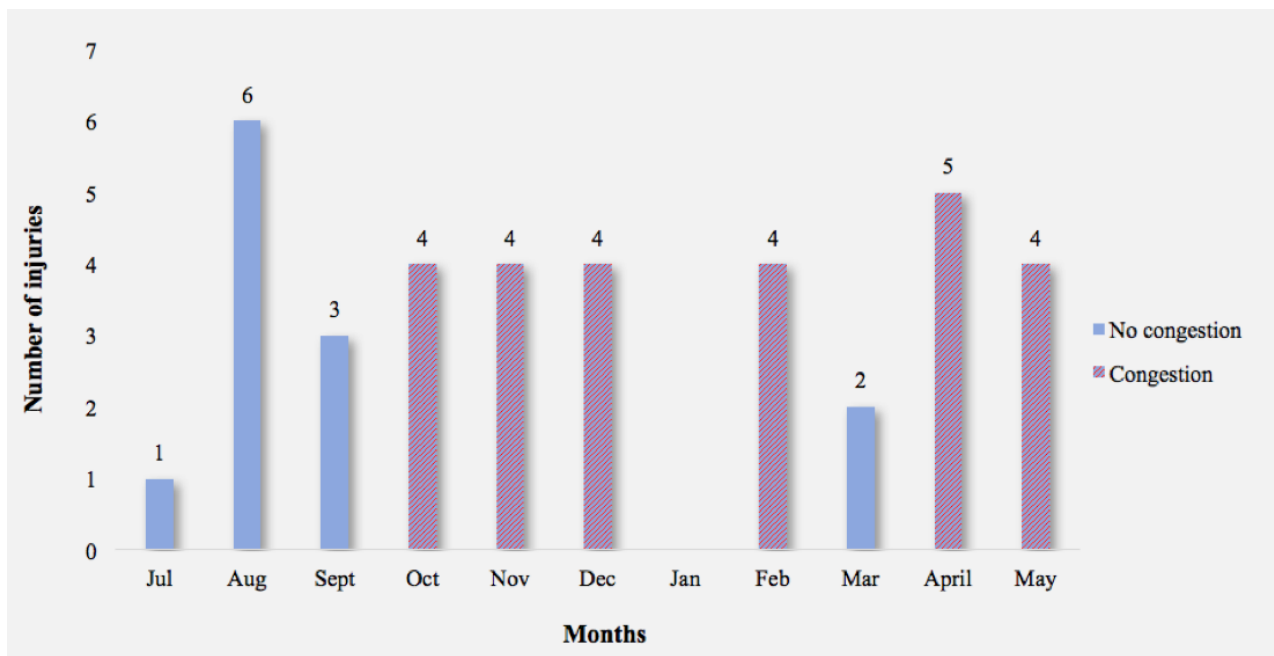
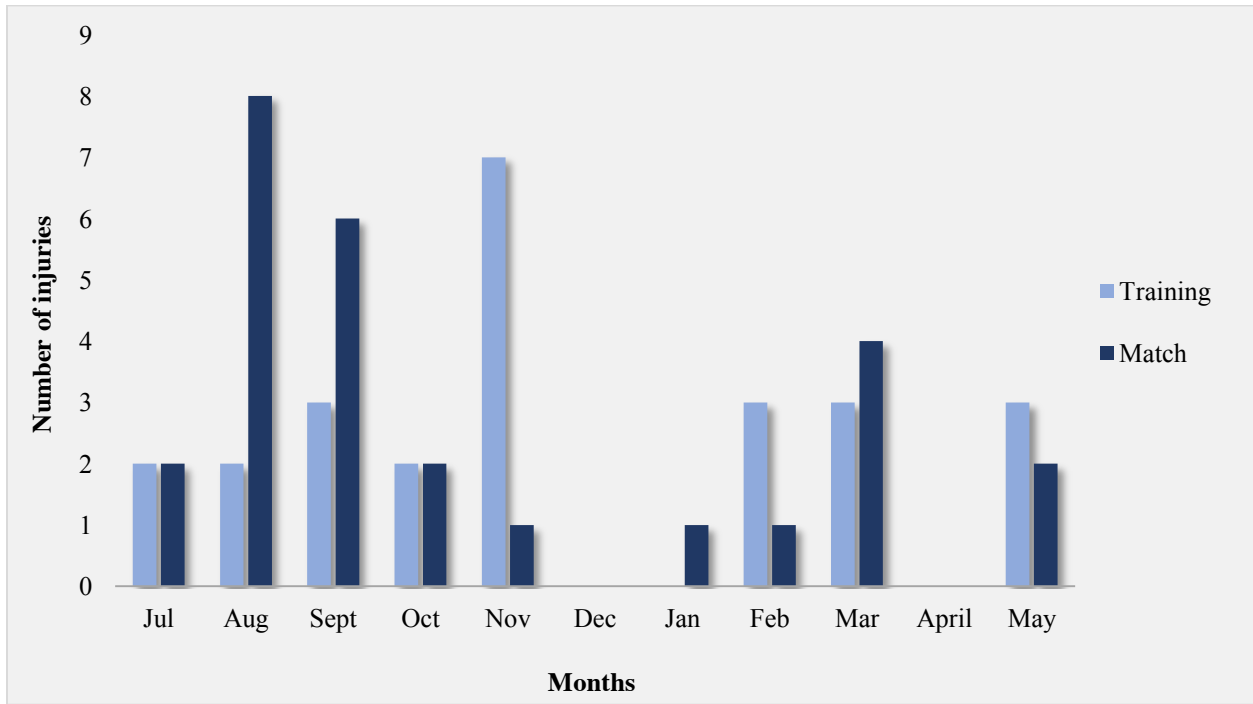


Figure 7a Injuries sustained during training or match per month, **b** Number of matches played per month and six months consisting of congestion

10.2.1 Training and match injury exposure and incidence

Multiplying the number of players ($n = 32$), the match duration (90 min) and the number of matches (31) results in 89 280 exposure minutes or 1 488 hours in total for the team. This equates to 2 790 match play exposure minutes per player during the season. The overall match injury exposure for all players was 1 023 match hours which results in on average of 46,5 match play exposure hours per player for the full season.

On-field training overuse injury exposure was calculated by multiplying the number of players ($n = 32$), the average duration of an on-field training sessions (120 min) and the number of on-field training sessions (3 per week, 47 weeks in total) resulted in 541 440 minutes of on-field training exposure or 9 024 hours in total for the team and 282 hours per player. Besides the on-field training sessions the team has on average two strength training sessions per week (60 min) resulting in another 180 480 minutes of training exposure or an additional 3 008 hours in total for the team or 94 hours per player. Total training exposure was therefore 12 032 hours for the team or a total average of 376 hours per player for the full season.

10.2.2 Injuries incidence

Fifty-two overuse injuries were sustained throughout the season, resulting in 3.98 overuse injuries per 1 000 hours of overall exposure. Twenty-seven overuse injuries were sustained during match play, resulting in 26.4 injuries per 1 000 hours of match play. Twenty-five overuse injuries were sustained during training, resulting in 2.08 injuries per 1 000 hours of training.

Injury statistics were grouped by player predominant position in the team. Specifically, defenders ($n = 6$), midfielders ($n = 12$) and attackers ($n = 4$). Relative injury exposure was also calculated per number of players per playing position and per hours of training and match.

The absolute injury number for midfielders are much higher than for defenders and attackers, however, this is because of the fact that the team consisted of more midfielders compared to defenders and attackers (**figure 3a**). Nonetheless, the relative overuse injury risk per position is different. Attackers sustained 17.2 injuries per 1 000 match exposures and 2.12 per 1 000 hours of training. Midfielders sustained less overuse injuries per match and training exposure hours.

Midfielders sustained 10.7 injuries per 1 000 match exposure hours and 1.6 overuse injuries per 1 000 hours of training. Defenders sustained the most match injuries with 23.9 injuries per 1 000 hours of match play, but less relative training injuries at 1.77 per 1 000 hours of training (**figure 3b and c**).

10.2.3 ACWLR and injury risk

Chi-square analysis of ACWLR in the three weeks prior to the week of the injury did not predict overuse injury risk. Injury rates for total distance (external load), high speed sprints (external load) and sRPE (internal load) using Gabbett's sweet spot for ACWLR of 0.80-1.30 and the corresponding p values for Chi-square testing (range (0.06 – 0.95) are presented in **table 3a, b, c**.

There were no significant findings for ACWLR using the values established by Gabbett's one week, two weeks and three weeks prior to injury and subsequent injury risk.

TD ACWL	<0.8	0.8-1.3	>1.3	Total	p=0.10
Injured	3,00	32,00	3,00	38,00	
Not-injured	134,00	419,00	58,00	611,00	
Sprint ACWL					p=0.12
Injured	4,00	29,00	5,00	38,00	
Not-injured	154,00	385,00	72,00	611,00	
sRPE ACWL					p=0.21
Injured	3,00	34,00	1,00	38,00	
Not-injured	93,00	466,00	43,00	602,00	

Table 3a ACWLR one-week prior to overuse injury using Gabbett's sweet spot

TD ACWL	<0.8	0.8-1.3	>1.3	Total	p=0.24
Injured	4,00	30,00	3,00	37,00	
Not-injured	134,00	421,00	58,00	613,00	
Sprint ACWL					p=0.12
Injured	4,00	29,00	4,00	37,00	
Not-injured	155,00	385,00	73,00	613,00	
sRPE ACWL					p=0.08
Injured	1,00	34,00	2,00	37,00	
Not-injured	95,00	465,00	42,00	602,00	

Table 3b ACWLR two-weeks prior to overuse injury using Gabbett's sweet spot

TD ACWL	<0.8	0.8-1.3	>1.3	Total	p=0.15
Injured	3,00	29,00	3,00	35,00	
Not-injured	135,00	421,00	58,00	614,00	
Sprint ACWL					p=0.78
Injured	8,00	22,00	5,00	35,00	
Not-injured	151,00	391,00	72,00	614,00	
sRPE ACWL					p=0.15
Injured	2,00	32,00	1,00	35,00	
Not-injured	94,00	466,00	43,00	603,00	

Table 3c ACWLR three-weeks prior to overuse injury using Gabbett's sweet spot

Injury rates for total distance (external load), high speed sprints (external load) and sRPE (internal load) using Malone's zone for ACWLR of 1.0-1.25 and the corresponding p values for qui-square testing (range (0.06 – 0.95) are presented in **table 4a, b, c.**

There were no significant findings for ACWLR using the values established by Malone one week, two weeks and three weeks prior to injury and subsequent injury risk.

TD ACWL	<1	1,0-1,25	>1,25	Total	p=0.95
Injured	22,00	12,00	4,00	38,00	
Not-injured	338,00	202,00	71,00	611,00	
Sprint ACWL					p=0.75
Injured	17,00	14,00	7,00	38,00	
Not-injured	311,00	206,00	94,00	611,00	
sRPE ACWL					p=0.35
Injured	19,00	18,00	1,00	38,00	
Not-injured	319,00	234,00	49,00	602,00	

Table 4a ACWLR one-week prior to overuse injury using Malone's zone

TD ACWL	<1	1,0-1,25	>1,25	Total	p=0.70
Injured	20,00	14,00	3,00	37,00	
Not-injured	341,00	200,00	72,00	613,00	
Sprint ACWL					p=0.06
Injured	13,00	19,00	5,00	37,00	
Not-injured	316,00	201,00	96,00	613,00	
sRPE ACWL					p=0.59
Injured	19,00	16,00	2,00	37,00	
Not-injured	318,00	236,00	48,00	602,00	

Table 4b ACWLR two-weeks prior to overuse injury using Malone’s zone

TD ACWL	<1	1,0-1,25	>1,25	Total	p=0.63
Injured	22,00	9,00	4,00	35,00	
Not-injured	339,00	204,00	71,00	614,00	
Sprint ACWL					p=0.22
Injured	13,00	14,00	8,00	35,00	
Not-injured	316,00	205,00	93,00	614,00	
sRPE ACWL					p=0.52
Injured	20,00	14,00	1,00	35,00	
Not-injured	317,00	237,00	49,00	603,00	

Table 4c ACWLR three-weeks prior to overuse injury using Malone’s zone

10.2.4 Qualitative assessment of individual player training load and injury risk

Week 1-7 is the pre-season and consisted of conditioning, friendly matches and conditioning training. The competitive seasons began in week 8, and the first official game was played on 22 August 2016 (week 8). The last official game of the competitive PSL season was played in week 46. Christmas break was over week 25 and 26 with return to training and match play in week 27. Therefore, there is a decreased TL over two weeks and an increase in TL in the following week for all players. This high increase of TL is not just because of the return to play after a two-week break but also because of the fact that during this break, the ITL and ETL was not measured and recorded and therefore not included in the analysis. Consequently, this will result in a visual “spike” in TL, however, is not described as a spike. We reported a mean distance during match play between 8 500- 10 500 m covered by midfielders, with peaks up to 13 000m. Attackers cover on average between 5 500m and 9 5000m with peaks up to 10 000m during match play. Defenders generally cover between 3 000m and 5 000m, with peaks up to 6 000m during match play.

The ACWLR in three only uninjured players (out of 22 players used for the analysis) generally varies between 0.70-1.30 (see **figure 10**) over the full competitive season without any excessive spikes compared to the 19 injured players with generally larger variations in ACWLR (see **figure 9, 12, 13**). The three uninjured players generally train and perform within Gabbett’s “sweet spot”. In addition, there were generally no increases or decreases in TL monitored of more than 20-30% per week and within weeks (see **figure 10**). In contrast, the 19 injured players never trained and competed for longer than three weeks within Gabbett’s “sweet spot”. In addition, they have TL increases and decreases of occasionally more than 30% per week or within weeks and/or do not have a consistent ratio between TDC and HIS acute:chronic workload ratio (see **figure 11**).

Defender A below (**figure 8**) is a player with a mean ACWLR of 0.96 with a highest ratio of 1.58 and a lowest ratio of 0.05. The standard deviation is 0.22 and the median of 0.97, which results in an ACWLR average within Gabbetts sweet spot and this is generally consistent. The player was playing within Gabbett’s sweet spot in week 13-15, however, there was a decreases of more than 30% over two weeks (week 16 and 17), which resulted in one overuse injury during the full competitive season.

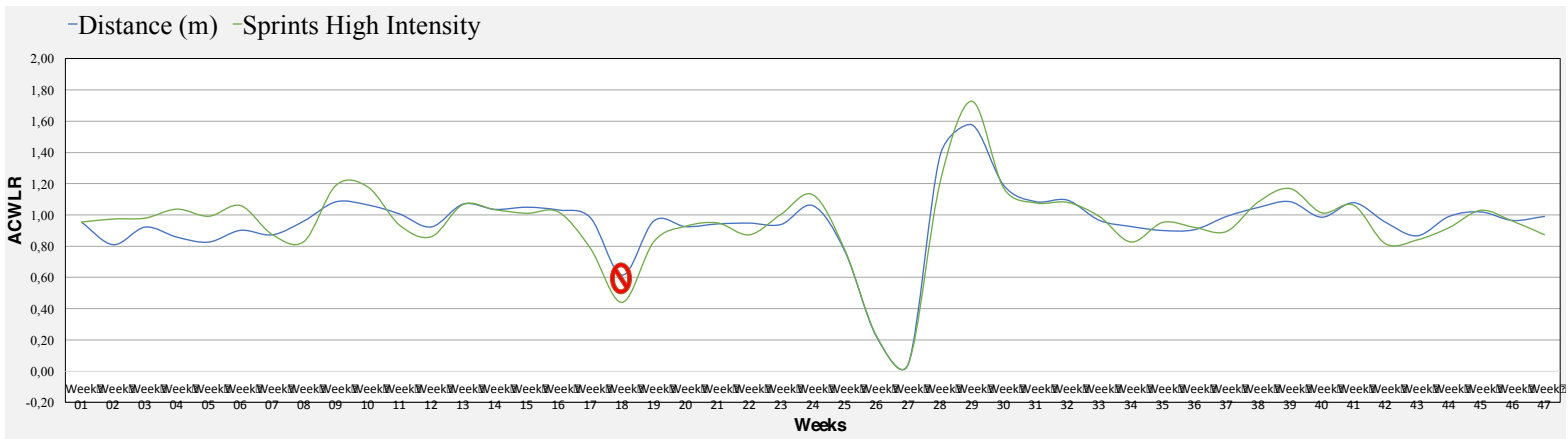


Figure 8 Defender A with an ACWLR mostly within the sweet spot (the red circle with line indicate the injury).

Defender B (**figure 9**) demonstrates multiple spikes in the ACWLR and trained and competed outside of the Gabbett’s sweet spot for many weeks for the majority of the season. In addition, defender B was exposed to many decreases and increases in TL of more than 30% per weeks. The mean ACWLR of this player is 0.92 with a high of 1.44 and a low of 0.06, standard deviation 0.24 and a median of 0.97. An interesting observation is a divergence between TDC

and HIS ACWLRs at various times throughout the season. This is most obvious from weeks 28 to 34. Defender B is covering more kilometers in week 13 and performs less HIS. In week 28-34, the player performs many HIS compared to the total distance, which results in an irregular ACWLR for external load. This high degree of variability was associated with five overuse injuries over the full competitive season.

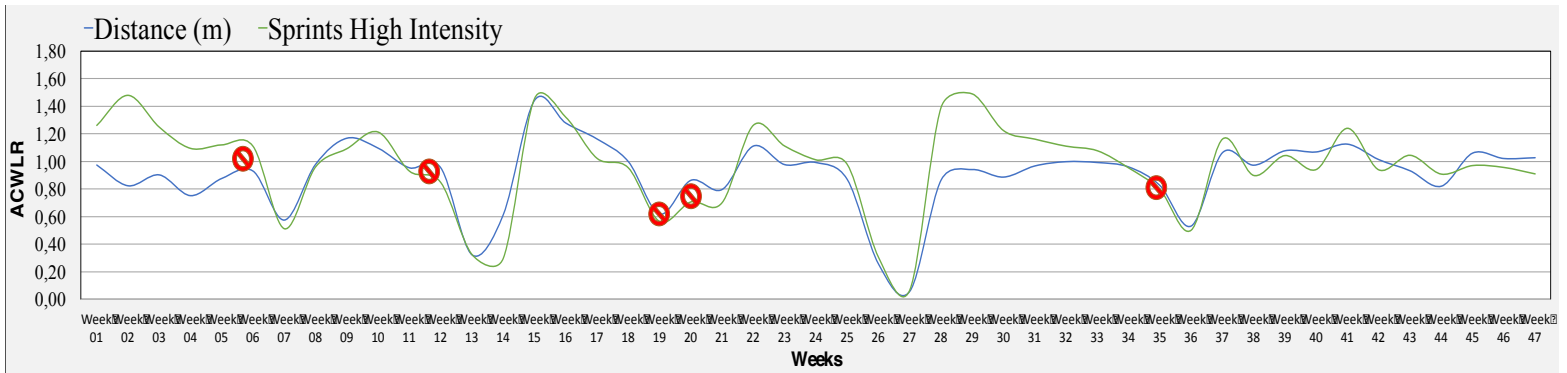


Figure 9 Defender B with many spikes during the full competitive PSL season, resulting in five overuse injuries (the red circle with line indicate the injury).

Midfielder A (**figure 10**) trained and competed mostly within Gabbett’s “sweet spot” during the season. The mean ACWLR of this player is 0.91 with a high acute of 1.10 and the lowest of 0.04, standard deviation of 0.18 and a median of 0.94 without many spikes. Compared to the other players, the ACWLR of this specific midfielder has no marked spikes after the Christmas holiday. The ACWLR increased to 1.40 after the break but stabilizes and returns to the sweet spot within two weeks. Both TDC and HIS acute:chronic workload remain relatively constant, without any large differences during the season. The steady ACWLR for this specific midfielder is related to no injuries throughout the season.

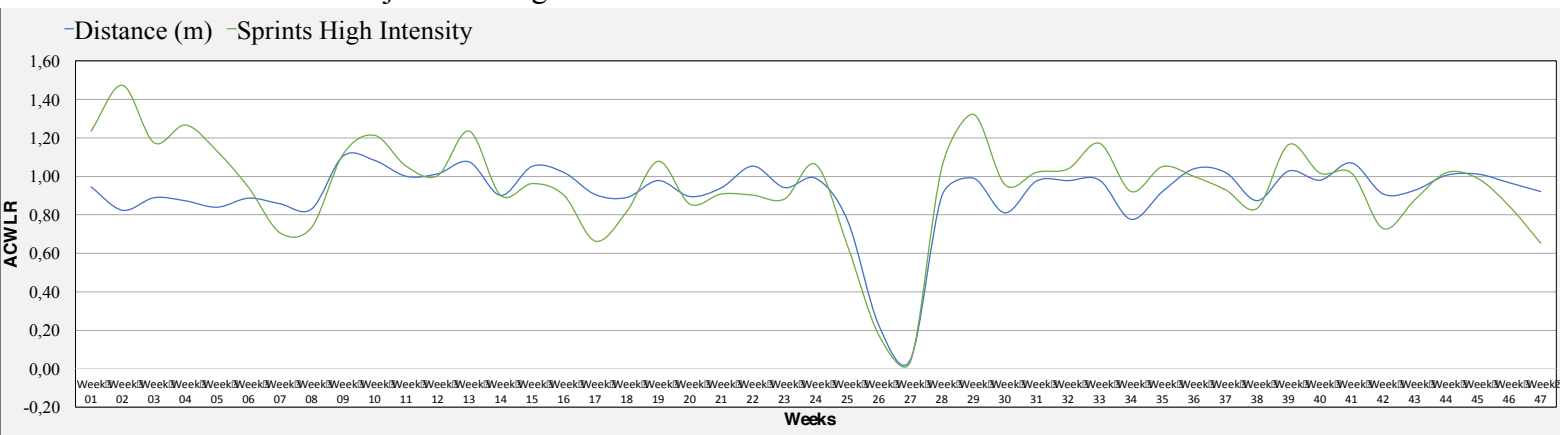


Figure 10 Midfielder A with an ACWLR within the sweet spot, resulting in no overuse injuries

Taking this into account, the consistent ratio of the midfielder mentioned above, midfielder B (**figure 11**) shows an ACWLR with large difference between TDC and HIS after the Christmas break in week 25 en 26. This player is not able to stabilize his ACWLR which may possibly have resulted in an overuse injury in week 37. Only in October is the player able to stabilize his load for four weeks.

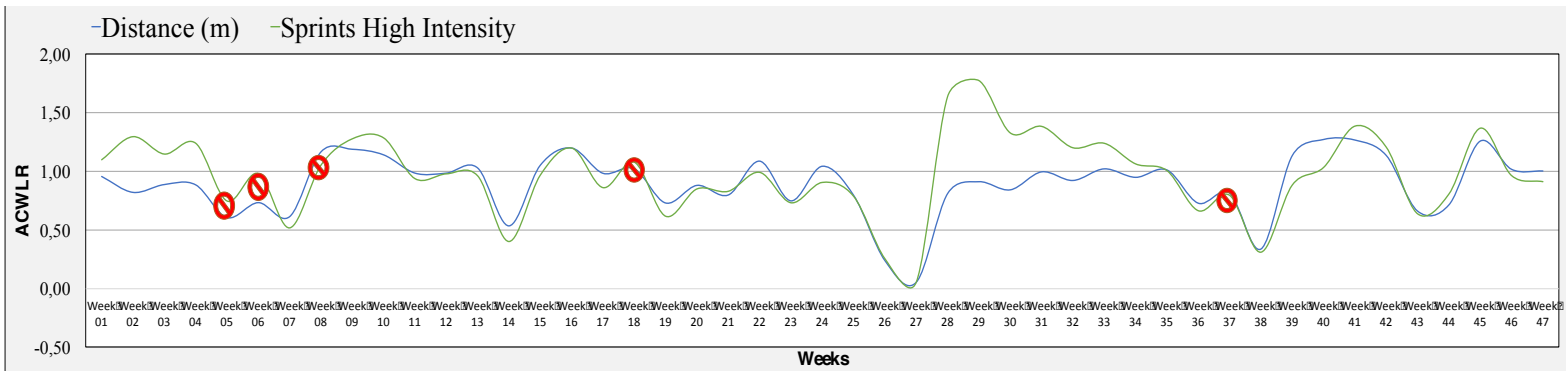


Figure 11 Midfielder B never trains within the sweet spot for longer than four weeks, without sustaining an overuse injury or with large difference between TDC and HIS ACWLR (the red circle with line indicate the injury).

The mean ACWLR for total distance of attacker A (**figure 12**) is 0.98 with a high acute of 1.59 and the lowest of 0.04. The median is 1.03 with a standard deviation of 0.30. In addition, the attacker shows large week to week differences, has at least five spikes in TL throughout the full competitive PSL season but only sustained one overuse injury in the beginning of the season. Interestingly, the acute:chronic workload ratio TDC and HIS is consistent during the season, without large differences.

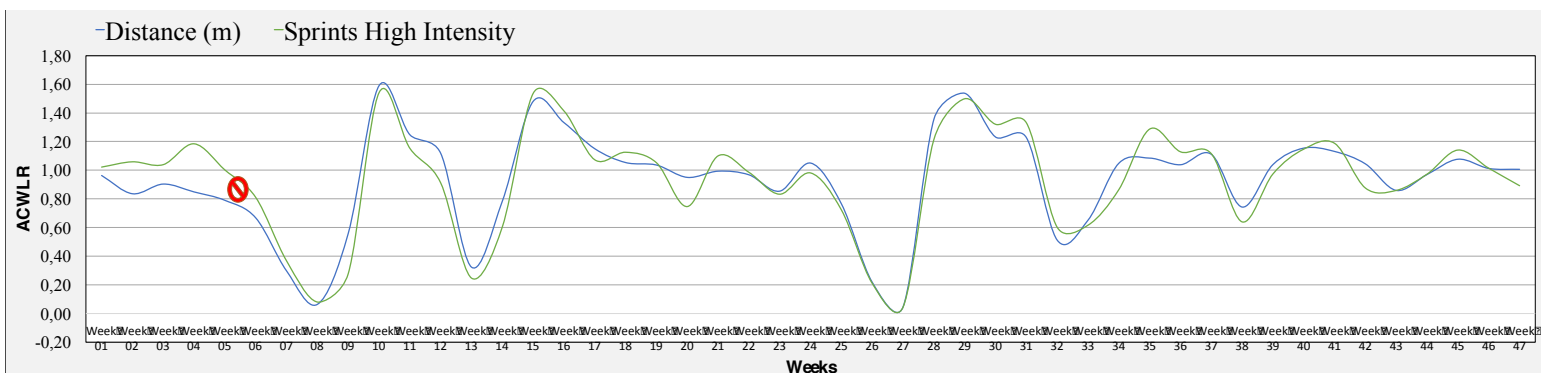


Figure 12 Attacker A with many spikes and large week to week differences in training load, sustained only one overuse injury in the beginning of the season (the red circle with line indicate the injury).

Attacker B (**figure 13**) sustained an overuse groin injury in the beginning of the season and was re-injured later in the season. Large changes in ETL are noticeable. In the first 33 weeks of the season the ACWLR for distance covered and high intensity sprints are similar. However, from week 36 the high-intensity sprints ACWLR is lower compared to the total distance ratio. The mean ACWLR of this player is 1.01 with a high acute of 2.00 and the lowest of 0.12. The median is 0.95 with a standard deviation of 0.43. These large differences between these outcomes may have contributed to three overuse injuries.

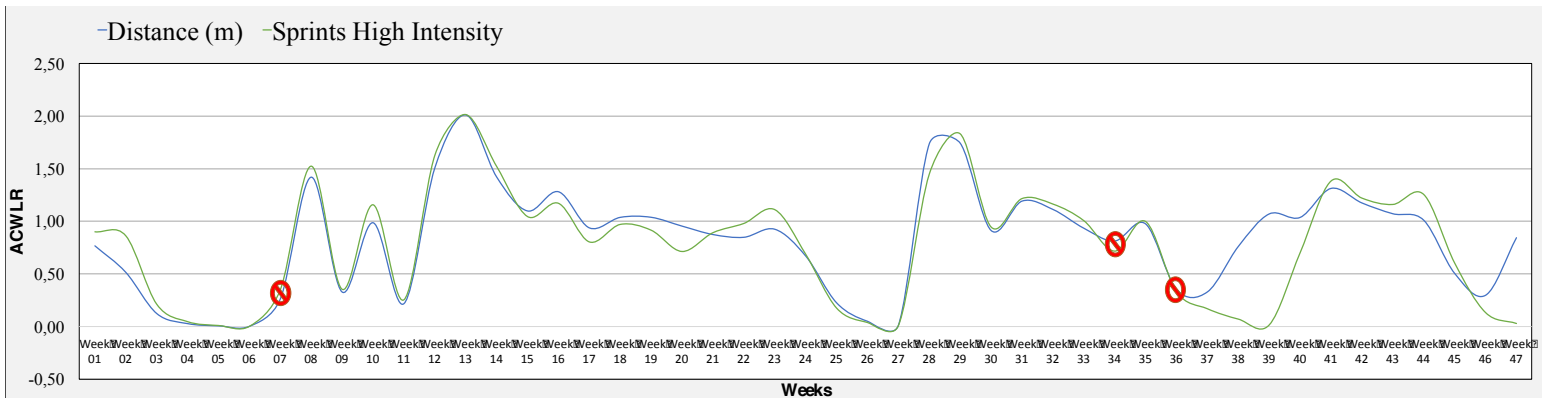


Figure 13 Attacker B with large spikes in TL (the red circle with line indicate the injury).

When comparing the six players above, their average total distance acute:chronic workload ratio is between 0.91-1.01 for all players. The biggest differences are demonstrated in their maximal ACWLR which differ from 1.10-2.00 and the standard deviation which varies from 0.18-1.43.

11. DISCUSSION

The objective of this study was to describe the pattern of overuse injuries in South African professional football. In addition, both internal and external load metrics were assessed for their ability to predict overuse injuries.

11.1 Descriptive injury data

11.1.1 Injury incidence

We recorded a total of 69 injuries during the full competitive season. Seventeen of these injuries were acute contact injuries. These injuries were not included in our study. Thus, a total of 52 overuse injuries were analysed in this study. However, as there is a lack of consensus on the definition of overuse injuries in football (O’Kane, et al., 2017), there may be a possibility that due to the definition and classification used in this study, injuries that do not strictly adhere to the definition of overuse injuries were included.

A previous study of professional South African football players by Calligeris, Burgess, and Lambert (2015) reported 130 injuries from all causes over a full competitive season. In contrast to our study, Calligeris (2015) reported all injuries sustained, including acute contact injuries and injuries affecting the upper extremity. As to our knowledge there is no other study on overuse injury incidence in South African professional football. Calligeris (2015) reported an overall injury rate of 13.4 injuries per 1 000 playing hours (Calligeris, Burgess, and Lambert (2015)). We found an overall overuse injury exposure of 3.98 per 1 000 hours, which is similar to the reported incidence of 2.70-8.70 injuries per 1 000 playing hours on average in studies of European football players (Ekstrand, Hägglund, & Waldén, 2011; Junge, et al., 2004). In addition, we found a significant difference between overuse injuries between matches and training with 26.4 overuse injuries per 1 000 match hours and 2.08 overuse injuries per 1 000 hours of training. The study by Fuller (2018) investigated the all causes injury incidence of English Premier League football clubs and reported a match injury incidence of 26.9/ 1 000 hours and a training injury incidence of 4.3/ 1 000 hours. This incidence is only marginally greater than our data, this is partly due to the fact that Fuller (2018) included all injuries. Nigerian football players sustain dramatically more injuries compared to both European and South African football players (Akodu, et al., 2012) with a rate of 55.2 per 1 000 playing hours (Akodu, et al., 2012). In

addition, European football players sustain on average 50-55 injuries per team per season (Ekstrand, Hägglund, & Waldén 2011). This is similar to South African football players in the study by Calligeris, Burgess, and Lambert, (2015) and the current study. Australian football players in the study by Lu et al (2017) sustained 39 non-contact injuries during the season, which is slightly less compared to our study.

Although the epidemiology of injury is extensively researched in professional football in Europe (Junge, & Dvorak, 2015; Ekstrand, Hägglund, & Waldén, 2011), there is limited research on this topic in Africa and South Africa respectively (Bayne, et al 2017). In addition, even in Europe, there is little research known about overuse injury incidence in professional football. As to our knowledge, other than the study by Gabbett, (2003) and Gabbett, & Jenkins (2011), that investigated overuse injury incidence in semi-professional and professional rugby players, there are very few studies known that investigated the overuse injury incidence in football players specifically. Thus, there are no studies available to compare our overuse injury incidence results with. Subsequent research should investigate the overuse injury incidence in professional football players.

11.1.2 Type of overuse injury

The types of overuse injuries in the current study were similar throughout the season. Hamstring and groin injuries are the most common overuse injuries recorded in this professional football team, which is similar to European studies that included both acute and overuse injuries. The study by Ekstrand et al (2011) and the study by Junge, & Dvorak (2015) reported most injuries affecting hamstrings, groins and calf muscles. Hamstrings are with 37% of all injuries, the most commonly affected muscles, followed by adductors (23%), quadriceps (19%) and calf muscles (13%) (Ekstrand, Hägglund, & Waldén, 2011). This is similar to the results of our study where 48.1% of the overuse injuries affected the hamstrings, 23.1% groin, 11.5% quadriceps and 5.8% calf muscles. In addition, 90% of these reported injuries affected the muscle tendon unit which is also similar to the reported injuries in our study. We reported 25 hamstring overuse injuries and only six injuries affecting the anterior side of the thigh (quadriceps) throughout the competitive season. These results are similar to the result of the study by Hägglund, et al (2013), that reported more hamstring injuries than quadriceps injuries and the study by van Dyk, et al (2018) that

reported 12% of all injuries affecting the hamstrings.

The recorded injury data for our study is similar to values reported in previous epidemiological studies in Europe. The match and training injury incidence are therefore likely to be representative for professional South African and European football (Fuller, 2018). Nonetheless, the studies by Ekstrand et al., (2011), Junge, & Dvorak (2015) and Fuller (2018) included all causes of injuries. As to our knowledge, there are no studies known that investigated the overuse injury types in professional football players, as there is a lack of consensus on the definition of overuse injuries. Subsequent research should investigate the types of overuse injuries in professional football players.

11.1.3 Severity of overuse injury

More than 50% of the injured players in our study returned to play after a minimum of eight days absence from training and competition. This is in line with the study by Fuller (2018) that reported that English Premier League football players return to play on average between 14 and 17 days post injury. Football players in the study by Lu, et al (2017) returned to play after suffering a non-contact injury after eight days. The study by Fuller (2018) states that no previous studies have investigated the median severity of injuries in professional football so there are no other values which the current study can compare to other than the study by Fuller (2018). In addition, the study by Fuller (2018) included all causes injuries and cannot confidently have been used to compare with our results. Subsequent research should investigate the overuse injury severity in professional football players.

11.2 Timing of overuse injuries related to training, match and season

Twenty-five of our reported injuries were sustained during training and 27 overuse injuries were sustained during match play. This is in line with the findings in the study by Lu et al., (2017) where 60% of all non-contact injuries were sustained during match play. Our findings are somewhat in contrast with the study by Ekstrand et al., (2011) that concluded that the incidence of muscle injuries is more than six times higher in match play compared to training. Out of the 27 overuse injuries sustained during match play in our study, 17 of these injuries affected the hamstring and six affected the groin. The study by Bowen (2016), Fuller (2006), Leventer,

(2016), Abbott, (2017) and Ekstrand, (2011) also concluded that hamstrings and groins are most often injured during match play. In contrast with hamstring and groin injuries, quadriceps, lower leg, ankle, and knee injuries occurred more often in training in our study. This is also in line with the findings in the study by Ekstrand, (2011), where hamstring and groin injuries were mostly sustained in match play.

We reported that hamstring and quadriceps injuries were consistently sustained throughout the full competitive season. Groin injuries were mostly sustained in the mid-season rather than pre-season and end-season. Lower leg injuries occurred either in pre-season or in the end of the season. In addition, a lower injury incidence mid-season may be explained by the fact that almost all our players were playing and training within the optimal TL (0.80-1.25) from February 2017 onwards. Additionally, there were no spikes recorded during match play, therefore, resulting in fewer injuries in both training and match play compared to pre-season. This is in line with the findings in the study by Murray et al., (2016) on injury occurrence in Australian football players where most injuries were sustained in pre-season relative to the number of injuries sustained in mid-season. In addition, the study by Murray et al., (2016) reported an average ACWLR of 2.0 in pre-season for most players, resulting in at least five times higher risk of injuries. This is in line with the results of our study where the risk of injuries was increased when the ACWLR exceeded 1.8 in pre-season.

There are numerous differences in training structure during either pre-season, in-season and after the Christmas break with regards to intensity, frequency and duration. Although most injuries in our study were sustained in pre-season, only one official league match was played, however, five friendly matches were played in August. As TL was increasing rapidly, most injuries were sustained in the first three months of the season. This supports the hypothesis of Gabbett, & Domrow, (2007) namely that the TL in the pre-season period is the greatest and training injuries in pre-season are therefore unavoidable. The study by Impellizzeri et al., (2005) also concluded that friendly matches were more regularly played in pre-season compared to in-season, which resulted in different periodization and overall TL during the full season. Consequently, resulting in many match injuries in pre-season.

In addition, in the second half of the season we only reported 16 overuse injuries compared to 36 overuse injuries in the first three months of the season. This is in line with the study by Murray (2016) that reported relative more injuries in pre-season compared to in-season. It may be assumed that an appropriate fitness level is reached in the second half of the season, therefore, resulting in a lower number of overuse injuries in our study. This highlights the need of an appropriate CTL to reach the peak demands to participate in matches where injury risk is unacceptable high.

In general, coaching staff can change the number, duration and content of training sessions but cannot influence the way both teams play during matches. In other words, it may be easier to prevent injuries in training and thus load during training needs to be adjusted to the demands of match play to ensure an adequate load, thereby reducing the risk of the occurrence of overuse injuries. We concluded that when the training frequency was reduced after the match frequency was increased, fewer injuries occurred in both training and competition. This is in line with the study by Muller (2018) that also concluded that fewer training sessions, in a period of high match frequency, reduce the risk of match or training injuries.

In conclusion, the nature of the training and match in either pre-season, in-season and end-season influences the risk and incidence of overuse injuries.

11.3 Optimal training load

This is one of the first studies to determine the influence of both ETL and ITL on the risk of overuse injuries in professional football. One other study (Jaspers, et al., 2018) utilized the same methods as our research study i.e GPS and sRPE training load metrics and overuse injury risk. Their findings indicated an increased risk of injury with high training loads at 2 and 4 weeks prior to injury for TD, sRPE and decelerations. However, that study utilised magnitude based inferences to determine injury risk. This statistical method has recently been contested and differs significantly to null hypothesis testing as used by our study as it has a high risk of type 1 error (Sainani, 2018). In contrast to the study by Jaspers, we did not find any statistically significant relationship between ACWLR for ITL or ETL and injury risk despite ACWLR being considered the best-practice approach to monitor and assess the relationship between TL and

injury risk in football.

Our finding was that ITL and ETL are not significantly associated with the occurrence of overuse injuries in professional football players within this team, which is in contrast to the studies by Gabbett, (2004), Gabbett, (2006), Gabbett, (2016) and Malone, (2017) that investigated and identified a significant relation between TL and injuries in professional football and rugby players.

However, our study may provide some support for the IOC consensus statement (Soligard, et al., 2016) regarding the association between an excessively increased TL and injury risk. The findings of our study of individual player TL may support the results found in other studies, namely, that a rapid increase or decrease (spikes) of TL could lead to an increased risk of overuse injuries (Fanchini, et al., 2018; Soligard, et al., 2016). To protect players from sustaining an injury, the study by Malone et al., (2017), discovered that an optimal ACWLR (1.0-1.25) protects against injuries in professional football players. Research in Australian Football, rugby and football have all concluded that high CTL may offer a protective effect against injuries (Murray, et al., 2016). This is in line with our findings for individual players where either an excessively high or excessively low ACWLR in either ITL and ETL were often associated with an increased number of overuse injuries.

As our study did not find any significant associations between sRPE ACWLR, HIS and TDC ACWLR and overuse injuries, we cannot recommend the use of the ACWLR monitoring to predict overuse injuries within a football team. This is in line with the findings in the study by Fanchini, et al., (2018), that also concluded that TL monitoring cannot confidently be used as a tool to predict injuries in individual football players within a team. To date, the study by Fanchini, et al., (2018) and our study are the only studies that have demonstrated that ACWLR is unlikely to predict injuries in professional football players within a team.

These findings emphasize the importance of future research on the association between TL and overuse injuries within a professional football team. Our recommendation is that individual player monitoring is recommended to avoid excessive spikes in TL as these may predispose to injury in some players as highlighted by our individual player analysis.

11.4 Different playing positions

11.4.1 Overuse injuries

To our knowledge, this is the first study that investigated the differences between playing position, ITL and ETL, ACWLR and overuse injuries in professional football. When analyzing individual player ACWLR over time, differences in both ETL and ITL outcomes were found and resulted in novel findings. The study by Bengtsson, (2013) reported the different demands of playing position within a football team and concluded that the demands varies excessively, therefore resulting in different injury incidence.

We reported the most (absolute terms) overuse injuries in midfielders, followed by defenders and attackers. However, the proportion of midfielders is in the majority and therefore injuries were calculated as per relative incidence. Then the relative number of overuse injuries is the highest among defenders in our study. This is in contrast with most studies in professional football in South America and Europe, where midfielders and attackers sustained most injuries (Carling et al., 2016; Morgan, & Oberlanders, 2001).

The high incidence of injuries in midfielders in these studies may be due to the fact that these studies may only have looked at the absolute number of injuries and not the relative number of injuries per playing position. In other words, most players within a team are midfielders and are able to be deployed as either defending midfielders or attacking midfielders. Resulting in a team which usually consists of more midfielders than attackers and defenders, which will consequently increase the number of injuries among midfielders.

11.4.2 Internal training load per playing position

All players in the current study, without taking into account their playing position, recorded a high- to very high sRPE (6-9) during match play and reported on average lower sRPE results (2-5) during training. This finding is in line with the findings by Fanchini, (2018). It may be assumed that very high sRPE results during match play, compared to relative low sRPE results during training, are associated with a higher risk of overuse injuries. Nonetheless, we did not find any significant outcomes to support this hypothesis for the team ITL average. However, our findings are in line with the study by Fanchini, (2018) that also did not find any significant

outcomes regarding sRPE results and overuse injuries. Although, monitoring ITL within a team is justified and valid enough to observe the increase in TL per week and should be the basis of players monitoring (Fanchini et al., 2018), monitoring the individual player and adjusting the individual's players TL is ideal. This is in line with the study by Fanchini et al., (2018) that provided justification for the implementation for an entire team monitoring strategy for ITL. The study concluded to be careful with making decisions for the individual player when using the team average. In addition, an association between ITL and injuries within a team cannot be used to represent the risk or predication of overuse injury risk at an individual player level.

11.4.3 External training load per playing position

The current study reported an average TL applied to all players within the team. When the average TL is prescribed for all players, some players may be overloaded and have consequently excessively high ACWLR. In contrast, other players may be under loaded resulting in low ACWLR, which may result in spikes in ATL during match play.

We reported a mean distance covered during match play between 8 500- 10 500 m, with peaks up to 13 000 m which is largely in line with the study by Bengtsson, (2013). They reported a mean distance of 10 000- 11 000 m with peaks up to 14 000 m. Attackers in our study sustained a relative high number of injuries during match play. This may be due to the high number of HIS and large average distance (7 500- 9 000 m) covered during match play. In addition, midfielders cover on average between 9 5000- 11 000m during match play. It may be assumed that midfielders are exposed to an adequate TL during the week. This adequate TL may consequently have resulted in the least relative injury risk during competition for our midfielders. Compared to attackers and midfielders, defenders covered the least distance during match play (4 500- 6 000 m), however, they sustained the most relative overuse injuries in our study.

There is limited research available to compare our overuse injury incidence among the different playing positions to other studies, as most studies, such as the study by Abbott, (2017) and Carling, (2010) only analysed the different demands of playing positions without taking into account the risk of overuse injuries. The study by Abbott, et al., (2017), Di Salvo, et al., (2007) and Leventer, et al., (2016) reported that defenders are more exposed to contact and jumps,

rather than HIS and are therefore at a lower risk to sustain overuse injuries. However, this is in contrast with the findings of our study. As the number of relative injuries is the highest among our defenders, it may be assumed that defenders are being under loaded during training and experienced spikes in ATL resulting in the highest number of overuse injuries during match play. However, there is no additional research to support this hypothesis.

As training sessions are generally the same for all players within a team, some players may have an optimal ETL and some may experience an inappropriate ETL. Training sessions consist generally of sprints, high intensity distance and repetitive acceleration and deceleration. The peak demands of match play for midfielders are most probably achieved during training. Midfielders are consequently exposed to adequate TL without spikes in ACL (match play), resulting in a lower number of match play injuries in our study. Ideally, the average per individual player should be calculated and on that basis, be prescribed during training sessions. In other words, it is more meaningful to analyze the physical demands for individual players and taking into account the relative match peak demands per playing position than the team average.

As we reported lower CTL during training compared to higher ATL during match play, it can be assumed that replicating peak demands of match play during training is still challenging and resulted in a high match injury incidence in our study. We concluded that when not reaching the peak demands of match play during training the risk of injuries in defenders was increased. This is in line with the study by Abbott, (2017) that concluded that training relative to average demands may lead to under preparation and therefore resulting in an increased risk of injuries in some players. Nonetheless, there is very little research on professional football players that investigated the ETL in relation to overuse injuries to support this hypothesis.

11.5 Individual players' ETL

By taking the variables of all the players mentioned above into account, avoiding spikes or large changes between weeks may reduce the risk of sustaining an index or recurrent overuse injury in the following weeks or later in the season. We concluded that large (>20%) week-to-week differences in ETL are associated with an increased injury risk. This is in line with the study by Rogalski, et al., (2013) that discovered that significant week-to-week variation in TL was

associated with an increased number of injuries in elite Australian football players (Rogalski, et al., 2013). Players in the current study were better able to tolerate a consistent level of ETL, whereby increases in TL of more than 20% resulted in a higher number of injuries. This confirms the results from the study by Veugelers, et al (2016), Blanch, & Gabbett (2016) and Abbott, et al., (2017), that all concluded that increases in TL of more than 20% negatively affected the injury incidence. However, our study only included overuse injuries, whereas the studies by Blanch, & Gabbett (2016) included all causes injuries. Therefore, comparing their outcomes to our results is not entirely reliable. Subsequent research should include and analyse overuse injuries in professional football players relative to ETL.

11.5.1 Differences between TDC and HIS

As to our knowledge, this is the first study that found an association between a large difference between TDC and HIS and the increased risk of overuse injuries within the individual players data. When analyzing individual player ACWLR over time, differences between TDC and HIS outcomes were found and resulted in novel findings. Our study discovered that a high TL on its own did not result in a higher risk of overuse injuries. This is in line with the study by Gabbett (2016). However, high CTL poorly distributed over the week in combination with large differences between TDC and HIS increased the risk of overuse injuries. In addition, overuse injuries in the current study were frequently reported after a period of disassociation of ETL, specifically when HIS was higher than the ACWLR total distance covered.

Defender B, mentioned above, experienced a difference of 20-40% in ACWLR between the TDC and the HIS a few weeks prior to the first injury and the fourth injury. It can be assumed that a difference in ACWLR of more than 20% between these two variables, occurring over a few weeks, may increase the risk of sustaining an overuse injury. In addition, it may also be assumed that being unable to stabilize the ACWLR and therefore not being able to avoid large differences between the TDC and HIS acute:chronic workload ratios, the risk of sustaining a subsequent injury may also be increased, which is seen in midfielder B.

In contrast to midfielder B, midfielder A and attacker A, have a consistent ETL (ACWLR for total distance covered and high-intensity sprints) throughout the full competitive season resulting

in one injury sustained by the attacker and none sustained by the midfielder respectively. However, these large changes in between TDC and HIS may have resulted in more injuries in another player. It may be assumed that because the fact that this attacker was able to stabilize the ACWLR of TDC and HIS, it may have been a protective mechanism against injuries for this specific attacker. Nonetheless as the ACWLR is not consistent to all players, it may confound the ability to prevent injuries within a team. Furthermore, this highlights the importance of monitoring the individual player instead of the team as a whole.

In addition, large difference between the ACWLR of TDC and HIS seen in attacker B resulted in three overuse injuries. The player had a higher ACWLR for total distance covered compared to HIS. It may be assumed that the player is already experiencing being over- or under loaded and is therefore performing less HIS. A low ACWLR for HIS may have reduced the risk of overuse injuries in our study. This finding is in line with the study by Bengtsson et al., (2013) that hypothesized that the reduction in HIS may result in a decreased injury risk.

Further research in professional football should investigate and identify the most optimal TL for individual football players within a team and thereby take into account the peak demands per playing position. Although there is very little known about playing position in professional football, there is evidence regarding this topic in rugby. The study by Gabbett, & Domrow (2007) included rugby league players to identify the relationship between TL and injury. The study divided rugby league players into three groups according to the physical demands of their individual playing position. Further research in professional football should subdivide defenders, midfielders and attackers, as seen in rugby, to monitor and assess the different physiological demands of football specific positions.

In conclusion, understanding the response of the ETL placed on a player may provide information that the coaching staff, and conditioning and medical team can use to determine if a player is exposed to an adequate TL. Our data demonstrates individual players assessment should be considered as it is an important method to reduce injury risk instead of the team as a whole.

11.6 Mismatch in training loads after injury

Some of the players in the current study sustained an injury, received treatment, returned to play and suffered a recurrent overuse injury. In the different phases of rehabilitation, the prescribed TL may differ between medical team members and strength and conditioning coaches. Due to the injury, the TL drops in the first phase of rehabilitation when medical team members, such as physiotherapists, treat the injured players. Since it would be impossible to maintain average HIS and TD for an injured player, TL will first drop followed by a rapid increase later in the rehabilitation. Not enough time is allowed for TL to return to necessary levels, after injury. As TL prescribed by physiotherapist and strength and conditioning coaches differs between phases in the rehabilitation, spikes in TL may occur when players proceed to the next phase in the rehabilitation (Gabbett, et al., 2016). After injury, players proceed to the phase where strength and conditioning coaches aim to prescribe higher TL than the medical team members to ensure average HIS and TD. This may result in a mismatch between TL after injury which consequently results in spikes in TL. In other words, both the conditioning team members and the medical team members are responsible for spikes in TL which results in higher overuse injury risk.

In this regard, the current study discovered a mismatch between TL from rehabilitation phase to return to play phase in a few players. The rapid increase in TL after treatment of an injury resulted in four overuse injuries in two midfielders, one defender and one attacker. One midfielder (figure 11) sustained a hamstring overuse injury when the external ACWLR 0.79 was, returned to play with an increase in TL of 30%, followed by a decreased external ACWLR of 30% which consequently resulted in another hamstring overuse injury. All within four weeks of sustaining the index injury, rehabilitation and return to play. This may be due to the mismatch between TL prescribed by the medical team and strength and conditioning coaches. This finding is in line with the assumption by Gabbett, et al., (2016).

If TL errors can be predicted and consequently be adjusted in time, these errors may be preventable which may then decrease the risk of overuse injuries. This hypothesis is supported by Gabbett (2016) who reported the differences between prescribed TL by the medical team and the coaching staff and the increased risk of overuse injuries. However, as far as I know, the research by Gabbett, et al., (2016) is the only research that partly investigated this issue. Future

research is necessary to clarify this hypothesis and thus lead towards the resultant practical implementation

11.7 Match congestion

We did not find a significant association between overuse injury incidence and match congestion. This is in line with the study by Hulin, et al., (2016) that found no difference between either a normal week or a congestion week and injury rates. However, the study by McCall, et al., (2014) reported a significant increase in injury rates during match congestion. In addition, the study by Dupont (2010) also found a significant increase in injury rate if there were less than three days of recovery time between matches compared to more than six days of recovery. Nonetheless, the study by Murray et al., (2014) found, depending on the playing position, either an increased or a decreased number of injuries in a congestion week.

In conclusion, match congestion was not significantly associated with injury risk and incidence within our team. However, caution is advised if the TL is not adequately adjusted to an excessive increase in ATL during match congestion. If not adjusted, congestion may negatively affect the risk and incidence of overuse injuries. Nonetheless, as these studies are contradictory, further research is needed to investigate the effect of match congestion.

Limitations

The current study has some limitations as it did not take into account the training structure during different phases in the competitive season. ITL and ETL were analyzed as per duration without taking into account the specific content of the training sessions. The sample size was sufficient to ensure statistical power, however, a larger sample size would have allowed a better representation. Major limitation of this study is the terminology and classification of “overuse injuries”. There is a lack of consensus on the definition of an overuse injury in football.

Practical implications

Monitoring the ITL and ETL for the team as a whole should be the minimum standard, however, monitoring and assessing the individual player should be targeted. Training loads should be high enough to withstand peak demands of match play but not excessively high and potentially

resulting in an increased injury risk. In addition, increases in TL of more than 20% should be avoided. Therefore, a balanced TL for the individual players needs to be established. This may be achieved by creating a baseline of the peak demands of match play (TDC and HIS) per individual player, in according to the demands of their playing position. In addition, training sessions should aim to enhance relative high sRPE results, without having many fluctuations between TDC and HIS and large week-to-week differences in ACWLR.

12. CONCLUSION

This study reinforces the importance of load monitoring in professional football. Excessively high weekly loads and high increases during the competitive season should be avoided. Prescribing individual loads, therefore taking peak match play demands per playing position into account, should be encouraged. No significant outcomes for the team as a whole were found with regards to ACWLR and overuse injuries. Training loads should aim to have a high CTL, to withstand the peak demand of match play. Similar ACWLR for TDC and HIS should be aimed for, therefore preventing spikes of more than 20%. Monitoring the individual player and predicting overuse injuries three, two and one week prior is essential in the prevention of overuse injuries in professional football players.

13. SUMMARY

The ACWLR is not significantly related to overuse injury risk within this professional football study. We recommend that monitoring should focus on the individual player, taking their peak demands of match play into account, rather than the team average. Spikes in training load of more than 20% (both increases and decreases) should be avoided. The ACWLR of total distance and high intensity sprints should be similar, and differences of more than 10-20% between the two measurements should be avoided. Hamstrings and groins injuries are predominant and were sustained throughout the competitive season. Defenders sustained the most overuse injuries within the team relative to exposure time compared to attackers and midfielders. Congestion weeks did not predict overuse injury risk.

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APPENDICES

Appendix I: Ethical approval football database



UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Human Research Ethics Committee



Room E52-24 Old Main Building
Groote Schuur Hospital
Observatory 7925

Telephone [021] 406 6338 • **Facsimile** [021] 406 6411

Email: nosi.tsama@uct.ac.za

Website: www.health.uct.ac.za/fhs/research/humanethics/forms

07 July 2016

REF NO: R028/2016

Dr J Swart
Human Biology
Sports Science Institute

Dear Dr J Swart

PROJECT TITLE: UNIVERSITY OF CAPE TOWN/AJAX FOOTBALL DATABASE

Thank you submitting your registry to the Faculty of Health Sciences Human Research Ethics Committee for review.

The HREC has **approved** the registration of your database.

Please Note: All research, including that undertaken for a master's or doctoral degree, using registered databases, registries and repositories, requires submission as a new study. It requires an application form ([FHS013](#)) and a protocol which has undergone departmental review. The study will receive its own HREC REF number which will be linked to the main database or repository.

The registration of this database is valid until **30 July 2019**.

Please quote the HREC reference number in all your correspondence.

Yours sincerely

pp T. Burgess

PROFESSOR M BLOCKMAN
CHAIRPERSON, FHS HUMAN RESEARCH ETHICS COMMITTEE

Appendix II: Ethical approval study



UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Human Research Ethics Committee



Room E53-46 Old Main Building
Grootte Schuur Hospital
Observatory 7925
Telephone [021] 406 6492
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Website: www.health.uct.ac.za/fhs/research/humanethics/forms

18 December 2017

HREC REF:809/2017

Dr J Swart
Human Biology
Sports Science Institute
Newlands

Dear Dr Swart

PROJECT TITLE: INTERNAL AND EXTERNAL LOAD MEASURES AS PREDICTORS OF OVERUSE INJURY RISK IN PROFESSIONAL FOOTBALL PLAYERS (MSc-candidate-C Varekamp)

Thank you for submitting your study to the Faculty of Health Sciences Human Research Ethics Committee (HREC) for review.

It is a pleasure to Inform you that the HREC has **formally approved** the above-mentioned study.

Approval is granted for one year until the 30 December 2018.

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.

(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

We acknowledge that the student: - Charlene Varekamp will also be involved in this study.

Please quote the HREC REF in all your correspondence.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please note that for all studies approved by the HREC, the principal investigator **must** obtain appropriate institutional approval, where necessary, before the research may occur.

Yours sincerely

U. Burger
PP **PROFESSOR M BLOCKMAN**
CHAIRPERSON, FHS HUMAN RESEARCH ETHICS COMMITTEE

Federal Wide Assurance Number: FWA00001637.
Institutional Review Board (IRB) number: IRB00001938

HREC 809/2017

Appendix III: Informed consent football database

INFORMED CONSENT FORM

University of Cape Town /AJAX football database

UCT Division of Exercise Science And Sports Medicine

Department Of Human Biology, Faculty of Health Sciences

University Of Cape Town

Dear Athlete,

During the course of your training and competition, information is collected regarding your total exercise time and intensity, strength and fitness. The medical team will also collect information during the course of the season relating to any injuries you sustain and treatment you receive for these injuries. We are requesting your permission to store this information in a database which may be used at some time in the future for research purposes. The specifics of the research have not been established at this time.

Why is this database being formed?

Your data might provide researchers with important information relating to football performance and the health and safety of players and potential ways in which performance, health and safety might be improved.

What will happen if you take part?

Your information (as described above) will be stored in an electronic database. Your participation in this database will not influence how the information is collected or stored by the club during their routine duties. It will also not influence your training or medical treatment in any way whatsoever. From time to time when a specific research study is designed and approved by the UCT Human Research Ethics Committee (HREC), relevant information from the database relating to your training or any injuries you have sustained may be extracted.

How your data will be shared with researchers:

When data is requested for a specific research project, a researcher will access your records and copy the important information relating to the study by filling in a research form or by copying this data into another electronic format such as an Excel spread sheet or similar document. During the transfer of this information your name and any details, which could identify you, will be removed from the data.

What will happen to my data and test results?

All information that is extracted from the database for research will remain confidential. You retain the right at all times to request that your data be removed from the database. All data that are extracted for research projects will be stored in a single password protected electronic database for a period of 48 months after which it will be erased.

Will you receive any reward for taking part in this database?

There is no financial compensation for participating in this database. However, any research studies generated from the database may improve coaching and medical management of football participants around the World.

What happens if I refuse to take part?

You are under no obligation to take part. If you decide not to take part, you will not be penalised.

What if something goes wrong?

There will not be any expected adverse effects as this study will only be an observation and will not affect any activities which you perform with the club on a daily basis.

Questions or Concerns:

If at any time you have any questions about the database, please feel free to contact any of the individuals listed below. You are assured that all inquiries will remain confidential.

Dr Jeroen Swart

Physical Address: Sports Science Institute South Africa

Boundary Road, Newlands

Tel number: +27 (0) 21 6595644

Email: jeroen.swart@uct.ac.za

Professor Marc Blockman

Chairperson, Faculty of Health Sciences Human Research Ethics Committee

Tel number: (021) 4066492

E-mail: marc.blockman@uct.ac.za

By placing your signature below, it serves as confirmation that you have had adequate time to read through this information, that you have understood the consent form and that you are willing to participate in this database. You have the right to withdraw at any time and you may ask questions at any time. All information removed from the database for research will remain confidential, and you will not be identified in any research which is published. Your signature is confirmation that you have read this informed consent and agree to participate in this database and any research study that might be generated from this.

Signature

Name (Please Print)

Date

Appendix IV: Session Rating Perceived Exertion

Rating	Description
0	NOTHING AT ALL
0.5	VERY, VERY LIGHT
1	VERY LIGHT
2	FAIRLY LIGHT
3	MODERATE
4	SOMEWHAT HARD
5	HARD
6	
7	VERY HARD
8	
9	
10	VERY VERY HARD (MAXIMAL)