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MASTER THESIS

QUANTIFICATION OF ECCENTRIC LOAD USING ACCELEROMETER IMBEDDED IN GPS

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ABSTRACT

Global positioning system (GPS) with a triaxial accelerometer is widely used to monitor movements of athletes in games and training, and "body load" (BL) representing the accumulation of the rate of changes in three planes of movements is obtained to determine the training load of a session. Deceleration, change of directions and stopping require eccentric contractions of leg muscles, potentially causing muscle damage and affecting athletic performance. Thus, it is important to monitor eccentric loading in games and training. A variable known as "eccentric index" (EI) purports to be a better representation of eccentric loading than BL. However, it is not known whether BL or EI accurately represents eccentric loading. The present study compared BL and EI during a drill consisting of several movements requiring eccentric contractions of leg muscles (Study 1), and monitored BL and EI over four training sessions of football (soccer) together with changes in maximal voluntary contraction (MVC) strength of the knee extensors and muscle soreness of the thigh muscles before and after each training session (Study 2).

In Study 1, 11 university students performed a drill consisting of 3 segments separated by 2 vertical jumps (segment 1: 70 m, segment 2: 50 m, segment 3: 60 m) with several movements including half turns (approximately 45°), 90° and 180° turns and a stop for a total distance of 180 m. All subjects performed the drill at 30%, 60% and 100% of their perceived maximal velocity, 2 trials for each velocity with a 5-min rest between trials. The same trials were repeated on two different days separated by at least 2 days. The time to complete the drill was measured by timing gates, and the time to complete each segment and entire distance, BL (GPSports, Australia) and EI (Athletic Data Innovations, Australia) of each segment were calculated from the GPS/accelerometer data using a specific software. One-way ANOVA compared the three velocities and three segments for the time, BL and EI, and a

Pearson product-moment correlation was used to examine the relationships between them. The time to complete the drill was 102.9 ± 15.2 s for 30%, 56.3 ± 5.6 s for 60%, and 42.6 ± 3.1 s for maximum (100%) velocity, with each significantly different from the others ($p<0.05$). A significant ($p<0.05$) difference was found between 30% (8.3 AU) and 100% (17.2 AU) velocities for BL, while a significant difference ($p<0.05$) between all velocities was evident for EI. Between segments for each velocity, no differences were found for BL, but for EI, a significant ($p<0.05$) difference was found between segments 1 and 2 for 60%, and between segments 2 and 3 for 100% velocity. The video analysis showed that the higher the velocity, the greater the knee bend during 180° turn and complete stop. It appeared that eccentric loading during change of directions and a stop increased with increasing in the running velocity. It seems that EI is a more sensitive measure of eccentric loading than BL.

In Study 2, 6 state league level outfield football (soccer) players were monitored for 4 training sessions, each lasting for 90-120 minutes. BL and EI were calculated as per Study 1 and MVC strength and muscle soreness were assessed before and 1 day after each training session. BL and EI were similar across the 4 sessions; however a large variability in the EI was evident among the players. It was found that a high EI player had a high total mechanical work (total accumulation of changes of directions, accelerations and decelerations). No significant correlation was found between BL and EI, indicating that BL and EI showed different aspects of the movements. No significant changes in MVC strength and muscle soreness were observed after any training session, suggesting that muscle damage was not induced, because of the protective effect conferred by regular training.

From the two studies, it was concluded that EI was a better marker to quantify eccentric load than BL, however it is still unclear how accurately EI represents actual muscle damage of leg muscles, which warrants further studies.

DECLARATION

I certify that this thesis does not, to the best of my knowledge and belief:

i. incorporate without acknowledgement any material previously submitted for a degree or diploma in any institution of higher education;

ii. contain any material previously published or written by another person except where due reference is made in the text; or

iii. contain any defamatory material

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CHAPTER 1

1. INTRODUCTION

1.1 Background

Many team sports such as football (soccer), rugby, hockey and Australian Rules Football (ARF) comprise short duration sprints, multiple changes of direction (CoD) and jumps (Andrzejewski et al., 2013; Dellal et al., 2011; Dellal et al., 2012; Howatson & Milak, 2009; Montgomery et al., 2010; Thorpe & Sunderland, 2012). For example, football is a high-intensity intermittent sport (Ispirlidis et al., 2008), and requires high-intensity, short-burst running and frequent accelerations and decelerations to perform explosive actions such as jumping, kicking, tackling, turning and sliding to win the ball (Bloomfield et al., 2008; Gatz, 2009; Stolen et al., 2005). It is reported that a sprint bout during a football game occurs approximately every 90 seconds (Bangsbo et al., 1991; Wong & Wong, 2009) and a player performs approximately 15 tackles, 10 headers, 50 involvements or touches with the ball and about 30 passes with frequent changes of speed (Stolen et al., 2005). Bloomfield et al. (2007) reported that English football players, as a team, performed a total mean of 727 turns and swerves within a match. Although explosive actions such as sprinting and quick CoD comprise a relatively small portion (<12%) of the entire activities (Bangsbo et al., 1991; Castagna et al., 2003; Gregson et al., 2010; Ispirlidis et al., 2008), they are considered to be important for achieving success in a game (Varley et al., 2012; Vigne et al., 2010). It is noteworthy that performing actions such as decelerating to a complete stop or CoD, and landing from jumps requires "eccentric contractions" (Lakomy & Haydon, 2004; Mougios, 2007; Roberts & Azizi, 2010).

Eccentric contractions occur when the force exerted by the muscle is smaller than the load on the muscle, or when the muscle is lengthened while generating force (Lindstedt et al., 2001; Roberts & Azizi, 2010). It is known that prolonged or intense eccentric contractions induce muscle damage that is characterised by delayed onset of muscle soreness (DOMS) and protracted decreases in muscle function such as muscle strength (Clarkson & Hubal, 2002; Proske & Morgan, 2001). Some of other indirect markers of muscle damage include increases in muscle enzymes such as creatine kinase (CK) activity and myoglobin in the blood (Mougios, 2007). Although the magnitude of muscle damage in athletes is smaller than that of untrained individuals after eccentric exercise, due to the protective adaptation conferred from regular resistance training (Newton et al., 2008), a loss of muscle function may affect performance significantly (Gastin et al., 2013), thus identifying muscle damage would seem prudent. In fact, it has been reported that muscle damage decreases performance of activities required in team sports (Ascensão et al., 2010; Rahnama et al., 2003; Reilly et al., 2008). However, since assessing muscle damage is a challenge in field settings, quantifying "eccentric loading" is an alternative, and if "eccentric loading" is correlated with changes in muscle damage markers, it may be possible to estimate muscle damage from monitoring "eccentric loading."

Eccentric loading to the lower limbs is observed when decelerating the body mass after sprinting, jumping or changing of direction (Roberts & Azizi, 2010). The aim of decelerating is to decrease the body's momentum (mass x velocity) by applying an opposite force over the shortest amount of time (force x time) to allow for a complete stop or to direct the momentum to a different direction (Griffith, 2005; Hewit et al., 2011). Therefore, it can be assumed that a higher force or greater eccentric contractions of the quadriceps and hamstrings is required to decelerate from a higher velocity in the same amount of time (Griffith, 2005;

Hewit et al., 2011). Colby et al. (2014) investigated injury risk based on running loads by monitoring 46 ARF players over a competitive season. The study utilised Global Positioning System (GPS) and accelerometer data to quantify the amount of workload accumulated over a season and examined the relationship between injury risks. The study reported two accelerometer-derived variables that were of interest, Force load (FL) which is defined as an accumulation of forces due to both foot strikes and collisions and relative velocity change (RVC) load, a calculated sum of acceleration, deceleration and CoD. It was reported that a 3-weekly running load, quantified by FL of >5,397 arbitrary units (AU) compared to <4561 AU or a 4-weekly RVC load of >102 AU compared to <84 AU was associated with 2.2-2.5 times greater injury risk during in-season. It was also reported that players who performed greater volumes of sprints during an ARF match or training had higher injury risk (Colby et al., 2014).

In a season, players have matches over 38 weeks on average in football (Football-Association, 2012; Thorpe & Sunderland, 2012), and, in addition, they perform training sessions between matches. Thus, it is essential for them to recover faster from matches and training sessions to avoid injuries and to remain fit throughout the season. Therefore, it seems important for coaches to quantify and monitor the amount of eccentric loading during matches and training sessions for each player throughout a season. In order to achieve this, a reliable method to monitor "eccentric loading" is necessary.

However, there is no gold standard of quantifying eccentric loading in a field-based environment. Practitioners utilise other measures of external load such as total distances travelled, total time spent in high velocity or total number of jumps (Vigne et al., 2010) to predict the possibility of a decrement in performance, and assume that this reflects eccentric loading. Currently, there are two major ways to quantify external loading in team sports using

tools such as motion analysis or GPS. Bangsbo et al. (1991) filmed 14 top-level players using 14 video cameras positioned near the side of the pitch and subsequently filmed the players after the game performing specific movements ranging from walking to sprinting for reference calibration values. The recorded images were then played back and coded for specific match activities (Bangsbo et al., 1991; Spencer et al., 2005). It was reported that movement profiles of football players differ according to playing position. This is especially prominent with forwards who performed significantly less backwards movements and headers compared to other positions (Bangsbo et al., 1991). A more recent study by Burgess et al. (2006) utilised Trak Performance Software (SportsTec Pty Ltd., Sydney) to quantify the profile of 45 individual football game performances. It was reported that a significantly greater number of effective passes were completed in the first half compared to the second half of the game (Burgess et al., 2006). With advances in technology, a GPS system is frequently used to quantify external loading in a more efficient manner. A GPS system with an incorporated accelerometer is able to quantify the accumulated external load of an athlete during a game by calculating the G forces the body sustains during play (Gomez-Piriz et al., 2011). Currently, GPS is used to quantify the various external loads in team sports such as total distance travelled, average speed, volume and intensity of sprints, and work to rest ratios (Aughey, 2011; Cunniffe et al., 2009; Thorpe & Sunderland, 2012; Varley & Aughey, 2013; Varley et al., 2012). The additional use of the accelerometer allows the GPS to generate a variable measuring the accumulated load of a player known as "Player Load" (PL) (Catapult Innovations, Australia) (Boyd et al., 2011; Young et al., 2012) or "Body Load" (BL) (GPSports, Australia) (Gomez-Piriz et al., 2011). Both PL and BL are derived from the accumulation of the rate of change in acceleration in the 3-axes detected by the imbedded

accelerometer. Both variables infer the load by adding the load of an axis in a second with other axial loads gathered at the same moment.

BL/PL are also used to monitor the accumulated volume and intensity of impact based tackles present in a game (Cunniffe et al., 2009; Kelly et al., 2012). Cunniffe et al. (2009) investigated the game demands of an elite rugby union game using data gathered from GPS. Data was collected from 2 players (1 back, 1 forward) of an elite team and showed that the forward accumulated a greater BL compared to the back due to the difference in positional requirements. Recently, studies have also demonstrated the use of PL/BL to identify the physical demands of the game, training load, and activity profile of the players (Aughey, 2011; Casamichana et al., 2013; Gomez-Piriz et al., 2011; Montgomery et al., 2010; Thorpe & Sunderland, 2012; Young et al., 2012). For example, Young et al. (2012) investigated the movement demands in ARF as indicators of muscle damage using GPS variables. A low correlation was reported between plasma CK activity at 24 hours post-match and the total BL of the low CK group (CK:188 IU/L, BL: 1070 AU) and high CK group (CK: 413 IU/L, BL: 1519 AU). Nevertheless, it was found that when the CK data was combined, CK had a large magnitude correlation with BL. However, it is not known how much PL/BL determined by the accumulated acceleration of the 3-planes represents eccentric loading.

Some elite sporting teams have enlisted private companies which provide analysis of GPS based data. Of these, a company known as Athletic Data Innovations developed a variable they refer to as the ‘eccentric index’ that purports to be a better representation of ‘eccentric load’ than BL/PL and claims to be a fairly accurate predictor for hamstring injuries in ARF (Colby et al., 2014). The eccentric index (EI) uses the rate of G force load collected during foot strike known as Force Load (FL), the rate of movement load based on both instantaneous velocity and body mass known as Motion Load (ML), and the rate of velocity

change during acceleration, deceleration and change of direction known as Mechanical Work (MW) (Gray, 2014). The developer of the 'eccentric index' (the associate supervisor of this thesis project) suggests that movements producing high load during foot strike, relatively low rate of movement load (low overall movement), and high velocity change during acceleration, deceleration and CoD induce significant eccentric load. However, no previous studies have systematically evaluated the validity and reliability of the "eccentric index."

1.2 Rationale of the Study

Although EI is not a widely used tool, it may have potential to be a better indicator of "eccentric loading" during team sport activities. However, EI has not been validated, and it is not known whether an exercise consisting of greater eccentric loading is represented by greater EI when compared with one of lower eccentric loading. Thus, the present study attempted to vary the eccentric load by manipulating the average velocity during a standardised drill.

A standard running drill was devised which included multiple changes of direction, 2 jumps and a complete stop with sprints interspaced ranging from 10 – 25m, a common distance found in the game of football (Andrzejewski et al., 2013; Castagna et al., 2003; Spencer et al., 2005; Vigne et al., 2010; Wong & Wong, 2009). This drill was repeated over 3 different velocities of increased intensity to reflect a higher eccentric load due to the need to decelerate from a higher velocity. Video analysis was included to investigate the magnitude of eccentric involvement during changes of direction between the various velocities. Although EI is not a widely used tool, it may have potential to be a better indicator of "eccentric loading" during team sport activities compared with the more commonly used BL. By comparing the relationship between BL/velocity and EI/velocity, the study attempted to

identify a better representation of eccentric load using the variables provided by the GPS and accelerometer. It is hypothesised that EI will produce a stronger correlation to the increasing velocity compared to BL.

This study also attempted to use EI in a practical setting by monitoring football (soccer) players over 4 training sessions. This was performed to establish a typical value of EI found in a training session and allow comparison of the values attained for each session with the perceived effort required of the session. The study will also compared the indices to markers of muscle damage such as MVC and muscle soreness as indicated by visual analogue scale (VAS) to determine the feasibility of BL or EI as a predictor of eccentric loading and extent of muscle damage.

1.3 Purpose

The overall purpose of the present study was to investigate the validity and accuracy of quantifying and estimating eccentric load based on accelerometer data from GPS devices by utilising BL or the less well known EI. The study aims to identify the index that better represents eccentric load to provide a more feasible field-based method to predict the magnitude of eccentric load and extent of muscle damage from training.

1.4 Research Questions and Hypotheses

The specific research questions to be answered by this research project were as follows;

- Does BL represent the total magnitude of eccentric load for actions such as CoD, jump and stops?
- Is EI a better representative of eccentric load?

- Will BL or EI be able to identify and quantify the magnitude of muscle damage after a training session?

This study hypothesised that;

- BL does not fully represent the magnitude of eccentric load for actions such as CoD, jump and stops.
- EI will be a better representation of eccentric load compared to BL.
- EI may be able to indicate some likeliness of muscle damage after a training session.

1.5 Significance of the Study

Results from the present study may enable coaches and strength and conditioning practitioners to better monitor the players' eccentric load during training and friendly matches using a tool that can be incorporated into training sessions. This in turn may provide valuable information to improve periodization over the course of a season. Furthermore, results for the study will provide data on the utility of accelerometer derived variables from the GPS device such as BL or EI as plausible indicators of eccentric loading or muscle damage after a training session.

CHAPTER 2
2. REVIEW OF LITERATURE

2.1 Eccentric Loading in Team Sports

During deceleration, muscles are lengthened due to the contractile force being lower than the external force, resulting in what is known as eccentric contractions (Moore & Wade, 1989). It has been reported that decelerations are as common as accelerations in team sports (Osgnach et al., 2010; Spencer et al., 2004), and decelerations may place significant mechanical stress on the body (Thompson et al., 1999). In intermittent team sports such as football, hockey or rugby, high velocity movements impose a physical strain upon the athletes and hence specific conditioning should be used to develop the ability to better perform such movements (Varley & Aughey, 2013). It has been suggested that high velocity running distance is associated with a higher standard of play in football with elite level players covering 28% more distance in a game compared with a lower level team. However, at the same level of play, a less successful team was found to perform more high-velocity running compared to a more successful or higher ranked team (Varley & Aughey, 2013). This is probably largely due to the fact that the less successful team has to perform higher velocity running in order to account for the difference in skills or other abilities of the more successful teams. Sprint efforts have also been identified as crucial for critical match activities such as getting to the ball first, manoeuvring past an opponent, or creating and attenuating goal scoring opportunities.

A correlation between the magnitude of increase in creatine kinase (CK) activity, a blood marker of muscle damage, and the number of sprints in a football match has been reported (Thorpe & Sunderland, 2012). However, it was shown that even though CK might

represent the presence of muscle damage, it is a poor predictor of the magnitude of muscle damage and the decrement in muscle function (Friden & Lieber, 2001). It was previously found that 76.9% of all after-motion from a sprint were a deceleration movement and 95.5% of all deceleration after locomotive movements were less than 2s (Bloomfield et al., 2007). This suggests that the eccentric muscle actions required during deceleration may lead to exercise induced muscle damage, resulting in possibly a decrease in an athlete's physical performance (Howatson & Milak, 2009; Ispirlidis et al., 2008).

2.2 Muscle Damage

Exercise-induced muscle damage occurs when eccentric muscle actions (eccentric contractions) are performed (Allen, 2001; Proske & Morgan, 2001). Exercise-induced muscle damage is characterised by symptoms such as delayed onset of muscle soreness (DOMS), prolonged decreases in muscle function, and frequently, swelling of exercised muscles (Clarkson & Hubal, 2002). Although histological examinations are required as direct markers of muscle damage, it is difficult to assess muscle damage by taking muscle biopsy samples due to the invasiveness of this process. Furthermore, the small sample of muscle tissue obtained by biopsy may not fully represent damage of the entire muscle (Clarkson & Hubal, 2002). Instead many studies have reported changes in indirect muscle damage markers such as increases in muscle soreness, CK activity and/or myoglobin concentration in the blood plasma, decreases in muscle strength, jumping performance after team sports such as football (Ascensão et al., 2010; Fatouros et al., 2010; Ispirlidis et al., 2008; Kraemer et al., 2004; Oliver et al., 2008; Rahnama et al., 2003; Thorpe & Sunderland, 2012), Australian Rules Football (Young et al., 2012) and rugby (McLellan et al., 2011), or simulated team sports activities such as repeated sprints (Howatson & Milak, 2009) and high intensity intermittent

shuttle running (Thompson et al., 1999). Research shows that some degree of muscle damage is induced after these activities, even for well-trained athletes.

However, a phenomenon known as the ‘repeated bout effect’ confers moderate protection after a bout of eccentric contractions (Nosaka & Aoki, 2011), and has been shown to be true for trained athletes (Nosaka et al., 2005). The repeated bout effect has been described as a protective effect where lower level symptoms of muscle damage and soreness will be evident after performing a repeated bout of the same exercise following a period of recovery (McHugh, 2003; McHugh et al., 1999). Therefore, it appears that the frequent training that athletes experience induces a repeated bout effect, lowering the degree of muscle damage even when eccentric loading is experienced during physical activity.

It is possible that some muscle damage induced in matches and training affects performance of team sports players (Twist & Eston, 2005). It has also been reported that accumulation of eccentric exercise-induced muscle damage could result in more severe muscle damage such as a muscle tear (Leadbetter, 1990). If this is the case then, it would seem prudent to monitor muscle damage of football players throughout a season. However, monitoring muscle damage is not straightforward, especially if several measurements are required. Furthermore, it was previously found that measures such as creatine kinase (CK) and delayed onset of muscle soreness (DOMS) are not good reflection of the magnitude of eccentric exercise-induced muscle damage or reduction in muscle function (Friden & Lieber, 2001; Nosaka et al., 2002). Since research has shown that eccentric contractions are the main cause of muscle damage (Clarkson & Sayers, 1999; Proske & Morgan, 2001), it is possible that the magnitude of muscle damage could be estimated by monitoring eccentric contractions.

Monitoring the total volume and intensity of eccentric contractions in a match or a training session may, therefore, provide valuable information relating to muscle damage. Movements consisting of eccentric actions are performed when changing direction, jumping, tackling and coming to a rapid stop during football matches and training (Reilly et al., 2000; Svensson & Drust, 2005; Thorpe & Sunderland, 2011). Such contractions used to decelerate and absorb shocks are mainly performed by activating the quadriceps, hamstrings and gastrocnemius muscles eccentrically (Griffith, 2005; Thompson et al., 1999). Hence, it would seem important to identify the frequency and magnitude of such eccentric loading during matches and training.

2.3 Time Motion Analysis

One commonly used method to identify the frequency of match activities with relatively high eccentric contractions involvement is the use of time motion analysis. Bangsbo and colleagues filmed 14 top-level players using 14 video cameras positioned near the side of the pitch and filmed them again after the game performing specific movements ranging from walking to sprinting for reference calibration values. The recorded images were then played back and coded by hand for specific match activities (Bangsbo et al., 1991). Similar methods were also used in quantifying work-rate in different positional roles in football matches (Reilly & Thomas, 1976). The use of manual based camera time motion analysis has expanded to include identification of playing formations, attacking moves and goal scoring patterns (Barris & Button, 2008). With the recent improvement in technology, computerised time motion analysis is now commonly utilised in team sports to evaluate the demands of the game as well as individual player's movement profile and performance (Barris & Button, 2008). Currently, there are two major categories within computerised systems. Software such

as SportsCode (Sportstec, Australia), Focus X2 (Elite Sports Analysis, UK) or ProZone (Prozone Sports Ltd , UK) does not automatically quantify a player's movement profile, but acts as a computerised format of the manual time motion analysis allowing for more efficient real-time and post-match analysis (Barris & Button, 2008). Other system such as Amisco (Sports Universal, France) feature a multi-camera system installed around the stadium and tracks all moving objects within the calibrated area (Barris & Button, 2008). Time-motion analysis systems utilising multiple cameras have been employed to report the frequencies of movements with eccentric involvement such as the number of repeated sprint bouts (4.2 ± 1.3) in field hockey (Spencer et al., 2004), total number of sprints (11.2 - 30.8) (Andrzejewski et al., 2013; Gregson et al., 2010; Rampinini et al., 2007), high intensity running (277 ± 66) (Bradley et al., 2009), and total number of sprints for defenders (83.1 ± 38.5), midfielders (84.1 ± 42.3) and forwards (72.6 ± 43.7) in football, respectively (Vigne et al., 2010). It can be accepted that time motion analysis is an effective method of quantifying the frequency of movement including an eccentric component, however, information provided by time-motion analysis systems does not quantify the magnitude of eccentric loading. In order to estimate the extent of muscle damage brought about by activities during matches and training, an alternate tool with the capability to quantify the magnitude of each eccentric movement is required.

2.3.1 Global Positioning System

Another possible method to monitor external load is to employ a global positioning system (GPS). Boyd et al. (2011) pointed out that although the GPS seems to be a convenient and valid tool for measuring and monitoring training load in intermittent sport, the reliability and validity of GPS as a tool decreases as the speed increases. This was also supported by other studies of Aughey (2011); and Varley et al. (2012). The apparent flaw of GPS also

includes the inability to account for contact based activities which occur during intermittent sports. However, this flaw may be partly overcome with the inclusion of a triaxial accelerometer, which most of the recent models of GPS have imbedded within the device. With the use of the accelerometer, measuring at 100Hz, GPS manufacturers developed a variable they claim measures the amount of accumulated load a player experiences during a session, referred to as Player Load (PL) (Catapult Innovations, Australia) or Body Load (BL) (GPSports, Australia). Body Load is calculated based on the acceleration data collected with the accelerometer using the formula;

$$\sqrt{((ax_{t=i+1} - ax_{t=i})^2 + (ay_{t=i+1} - ay_{t=i})^2 + (az_{t=i+1} - az_{t=i})^2)} \, / \, 100$$

Where ax, ay and az represent the acceleration in the x,y and z axes respectively, t representing time and i represents current time.

It is known that although both companies indicate that each of their variables represents the amount of accumulated load a player experiences (Coughlan et al., 2011; Gomez-Piriz et al., 2011), the algorithm of the variable is different. It was found that a device placed distally on a player's upper back region recorded slightly higher Player Load values, and this may indicate that attachment position is crucial in obtaining accurate results reflecting the lower body movements, and interpretation of the player load value may differ depending on position of attachment (Boyd et al., 2011; Netto et al., 2010). However, there are currently no studies that utilise PL or BL to quantify eccentric load. Indeed, it is not even currently known whether PL or BL are representative of eccentric load.

2.4 Measuring Load with Accelerometry in Contact Sports

The use of GPS also extends to evaluating performance and activity profiles in competitive games (Varley & Aughey, 2013). An example of the use of GPS in an 'on field' setting involved evaluating the physical demands in an elite rugby union game (Cunniffe et

al., 2009). The study recruited a total of 3 players from a league representing the highest standard of club play from the Celtic nations. Two sets of full data were collected due to the third player completing only a quarter of the entire match. The study utilized GPS to monitor an out-of-season 80 min competitive game, and collected variables such as, heart rate, locomotor activity, Body Load, game impacts and estimation of energy expenditure to represent the physical demands of an elite rugby union game. The notable aspect of the study is the use of GPS-accelerometry to evaluate the physical demands of a competitive game. The study showed that although usual measurements such as work to rest ratio provide important information on the demands of the game, calculating work to rest ratios based on player locomotor activity may underestimate actual work time, especially in a game such as rugby where a notable amount of time is spent pushing/pulling in rucks or scrums. These actions are noted to be intense static player efforts despite GPS results based on locomotor activity registering them as low intensity activity. Therefore, based on the review of Cunniffe et al. (2009) it may be that the use of accelerometers can better measure the aspect of impact or other aspects that usual methods might be unable to quantify. This, for example, could include the impacts each player sustains during tackles or the eccentric contractions performed during activities such as scrums.

To further investigate the practicality of GPS in quantifying load that is often unable to be captured using usual methods, a study was conducted in 2012 to develop an automatic detection model for collisions in elite level rugby union using a wearable sensing device such as GPS (Kelly et al., 2012). The study attempted to develop a reliable movement analysis model to automatically detect player tackles and load using these wearable sensing devices. This was achieved by comparing GPS data analyzed by various algorithms to video motion analysis collected with 3 players in elite level rugby union game in order to validate a suitable

model that would automatically detect, with minimal error, when a collision take place during a game. It was found that the model, ‘the learning grid’ developed by the team was able to achieve a precision score of 0.958 when compared with the traditional method of identifying collision using video motion analysis. The score achieved showed that the model is able to identify collisions consistently with very few false positives or negatives. The investigators noted that further research was warranted to apply the developed technique on other domains of movement classification. However, no research reported the magnitude of eccentric loading using this method.

2.5 Measuring Load with Accelerometry in Limited-Contact Sports

Besides utilising GPS in contact based sports such as rugby or Australian Rules football, GPS accelerometry is also used to evaluate demands in limited-contact sports or non-impact tackling aspects of a contact sport. Young et al. (2012) investigated the association between GPS variables describing movement demands of an elite junior ARF game and post-match CK levels sustained by the players (Young et al., 2012). The study monitored fourteen male elite junior Australian Rules Football players in a competitive game wearing GPS devices on their upper back via a specially designed vest. Plasma CK was collected 24 hrs post-match. Subjects were split into two groups (high CK, low CK) using a median based on each subjects’ CK results. It was found that the high CK group had greater scores in all GPS variables describing game movements, including player load (PL). The study noted that greater distances covered at various speeds and accelerations and decelerations were associated with greater muscle damage. Results of the study suggest that relatively high-intensity running and acceleration and deceleration across intensities are relatively large contributors of high plasma CK. The study also found weak correlations between high CK/PL

and low CK/PL. However, when results of CK were pooled, PL had a large magnitude correlation with CK. The study suggested that it is likely that the primary cause of muscle damage is high-intensity running, high acceleration and deceleration running, and running with changes of direction. Therefore, it would seem important to quantify the magnitude of the eccentric loading induced by these movements.

A recent study conducted by Cormack et al. (2014) investigated the usefulness of PL to quantify the activity profile in specific positions in netball. Furthermore, the study also attempted to assess the difference in standard of Netball match play using PL. A total of thirty-two netball players from four teams were recruited from two different standards of competition, namely, a higher Victorian state league championship and a lower recreation B grade competition. It was found that players playing in the centre position, where there were fewer restriction imposed on their movement, generally obtained higher PL. It was also found that PL provided a consistent and meaningful difference between the two different standards of play, indicating that PL may be an effective tool to evaluate the activity profile in Netball.

In another study, Montgomery et al. (2010) recruited eleven junior male players to attempt to characterize the physical and physiological demands of basketball training and competition. The study involved using GPS and HR monitors for 3 competitive games. Nine out of the 11 players recruited completed a series of unstructured offensive and defensive training drills instructed by the coach, and 7, 5on5 scrimmage competitions over 2 weeks played on a reduced size court for the assessment of basketball training. Unpublished observations obtained from the study's pilot trials noted that the accumulated load gathered from GPS was highly correlated to heart rate and blood lactate accumulated during 1on1 drills, and 2on2 scrimmage play. The study also found an increased demand in competitive games compared to 5on5 scrimmages based on player load data gathered. It was suggested

that the additional demands might be due to additional running up and down the full court during transition and increased movement intensity during offensive evasive, and defensive reactive movements. The study concluded that accelerometer technology combined with predicted values of oxygen demand is a useful tool for determining the demands of the game which could provide critical insight for the development and monitoring of training in basketball.

Another study investigated various methods of quantifying external and internal training load (Scott et al., 2013). The purpose of the study was to assess the use of GPS and accelerometry as a means to quantify external training load (TL) by comparing internal training load measures such as, the session rate of perceived exertion (sRPE) method and two heart rate (HR) based methods (Banister's TRIMP and Edwards' TRIMP) against accumulated accelerations (PL) and GPS measurements of player movements. The PL vector magnitude accumulates during skill-based movements, tackles, and other non-running activities and may therefore provide a better indication of the demands imposed by non-running activities than the GPS-based speed data alone. Fifteen football players from a professional team competing in the soccer A-league were recruited and monitored over 29 training sessions for a total of 97 individual sessions. The study found that PL is an acceptable measure of external TL and is largely related to players' physiological and perceptual responses to training stimuli in professional football. The large relationship between total distance travelled and accumulated PL found in the study (r=0.93) suggests that the magnitude of player load may be highly depend on accelerations measured from vertical motion (z-axis), which occurs due to the vertical decelerations generated by each heel strike. The study concluded that PL has a strong relationship with measures of internal TL and may

also reflect other high-intensity information not assessed by perceptual and physiological measures.

Casamichana et al. (2013) examined the relationship between PL with measures of internal load such as sRPE and TRIMP using Edward's method and external load such as total distance travelled, distance and frequency of instances travelled, at high and sprint speed ($\geq$18, $\geq$21 km.h^{-1}) and work to rest ratios in association football (Casamichana et al., 2013). Twenty eight semi-professional football players were recruited with a total of 44 individual training sessions monitored. The study found a large to very large association with sRPE, TRIMP and total distance, which showed the possibility of using PL to monitor training efforts in football players. Gomez-Piriz et al. (2011) investigated the relationship between total BL (TBL) and sRPE in football players. A total of 124 individual GPS data points (TBL) were collected from 22 professional male football players and all RPE measurements were collected using a 21-point scale 30 minutes after each training session. The rating was then multiplied by the length of the training session (min) to represent individual sRPE. It was found that the relationship between sRPE and TBL was significant but non-linear, and weak. The study suggested that TBL was not a valid tool for main coaches and fitness coaches to quantify exercise load during football-specific training, and that monitoring acceleration forces without considering further aspects that influence the overall exercise load may be insufficient to evaluate the training load of a player. Based on the formula for body load presented above, it can be assumed that the BL/PL variable represents not only eccentric load, but concentric and other impacts associated with body contact and running as well. This differs with eccentric load which considers only the eccentric phase of a movement such as deceleration and landing from a jump. With the wide use of PL/BL as a measure of the

amount of load sustained by players during training, there is a need to investigate the amount of eccentric load represented by PL/BL.

2.6 Eccentric Index

A company that provides analytical services for sports teams, Athletic Data Innovations, developed a variable they refer to as the ‘eccentric index’ that purports to be a better representation of ‘eccentric load’ than ‘body load’. The eccentric index (EI) uses the rate of G force load collected during foot strike analysis known as Force Load (FL), rate of movement load based on both instantaneous velocity and body mass known as Motion Load (ML) and rate of velocity change during acceleration, deceleration and change of direction known as Mechanical Work (MW) in an equation $EI = \frac{FL}{ML} \times MW \times scalingfactor$. The developer of the ‘eccentric index’ reports that movements producing high load during foot strike, relatively low rate of movement load (low overall movement) and high velocity change during acceleration, deceleration and change of direction will induce significant amount of eccentric load. However, the developer of EI reports that instead of an accumulated volume measure like BL, EI represents the average rate of eccentric loading of the recorded session. In order to obtain a volume measure similar to BL, EI will have to be multiplied by the duration of the session. In 2014, a study conducted by Colby et al. (2014) found that during in-season of ARF, players travelled a mean distance of 7205m, 13399m and a mean sprint distance (>75% of player’s maximum speed determined over 20m) of 90m, 268m during a main training session and Australian Football League (AFL) game respectively. The study measured components variables of EI such as FL and MW and reported that players who exert a 3-weekly FL of >5,397 AU compared to <4,561 AU had a 2.5 times greater injury risk. It was also shown that players having a 4-weekly relative velocity change load (MW) of >102 AU

had 2.2 times greater injury risk compared with <84AU (Colby et al., 2014). It may be that the ‘eccentric index’ represents eccentric load better than ‘body load’, and changes in muscle damage markers after a training session or a match may be better related to ‘eccentric index’ than ‘body load’. Therefore, investigation of the comparison between BL and EI may be able to clarify the amount of eccentric load BL represents and if EI proves to be a better representation of eccentric load compared with BL. However, to date no studies have validated EI.

2.7 Gaps in Literature

The current use of GPS in team sports encompasses the analysis of movement profile in a game, individual performance, individual movement profile and a possible gauge of training load. Incorporating accelerometry, a variable known as BL/PL can be generated which represents the accumulated load a player experience during a training session or game. However, currently, the use of PL/BL is mostly within the spectrum of contact-based team sport such as rugby and ARF, with special focus on body impacts. It was also found that PL/BL is associated with external load such as total distance travelled, plasma CK and sRPE. It was suggested that the accumulation of PL/BL may be due largely by the magnitude of vertical decelerations caused by the heel strike of each step. However, it is not known whether PL/BL can be used to indicate the amount of eccentric load caused by deceleration sustained in games or training sessions. As PL/BL is a variable based on the accumulated acceleration in all 3-axes measured by the imbedded accelerometer, it represents not only eccentric load, but concentric and other impacts associated with body contact and running. Therefore, investigation of an alternate variable such as the EI which purports to better represent eccentric load should be conducted to examine if a variable derived from GPS and

accelerometry can be utilized to quantify and monitor eccentric loading in a game/training session. Studies should focus on the representation of BL and EI as an indicator of eccentric loading induced by deceleration. Furthermore, additional research should be undertaken to investigate the prospect of utilising BL or EI as a monitoring and estimation tool for eccentric loading and muscle damage during training sessions and games.

CHAPTER 3

3. METHODS

3.1 STUDY 1

3.1.1 Participants

Eleven university students were recruited for the study from Edith Cowan University. Their mean (± SD) age, height and body mass were 26.2 ± 3.8 years, 174.9 ± 8.5 cm and 75.3 ± 12.8 kg, respectively. All participants were physically active and participated in recreational team sport activities such as football and baseball. No specific instructions were given to the participants for the testing days other than asking them not to perform any strenuous exercises before coming for testing. Permission to conduct the study was granted by the ECU Human Research Ethics Committee. The participants completed a written informed consent consistent with the principles set out in the Declaration of Helsinki prior to participation in the study. A minimum sample size of 10 was required and was determined using a sample size calculator (Raosoft Sample Size Calculator, Raosoft Inc, USA), with 95% confidence level and 5% margin of error to represent the number of outfield players in football.

3.1.2 Study Design

The study consisted of two sessions separated by 3-5 days, and all participants performed the running drill outlined below at three different velocities (30%, 60% and maximum velocity) with two trials for each velocity on each day. The participants performed a pre-determined running drill which incorporated movements found in team sports, including turns (change of directions), complete stop and jumps and, this was repeated on a separate day with at least 2 days recovery between sessions. The course was designed as an attempt to

include the variety of movements performed in a team sport match, therefore, a choice of various CoD from both directions and different magnitudes were chosen. Vertical jumps and complete stops were included to make the course more comprehensive. The study attempted a more field –based and practical approach to the problem rather than an isolated lab based approach as it was hypothesised that the understanding of the validity of the variables and the contribution of the various movements to the total load might transfer to assist in the understanding of monitoring a football training session.

The time to complete each trial was measured by timing gates, and the movements of each trial were recorded via a GPS device (GPSports SPI PRO X, Australia) with an on-board accelerometer. The participants wore football boots or baseball cleats for all tests to prevent slipping. In this experiment, the independent variable was the velocity of running, and the dependent variables included the time to complete the drill, body load (BL) and eccentric index (EI). The movements were recorded by a video camera (Sony HD 1080i, Japan), at a frame rate of 25 fps. The details are shown in sections below.

3.1.3 Running Drill

In session 1, the participants performed 3 maximal velocity tests over 25 m prior to performing the running drill. Participants commenced the maximal velocity test and running drill from 1 m behind the starting timing gate. They were asked to run through the length of 25m without decelerating until they passed through the final timing gate. A 2 min rest interval was provided before commencement of the next maximal velocity test. The mean velocity achieved over the 25 m distance was recorded, and the highest mean velocity of the three trials was used to set the 30% and 60% of maximum velocity for each participant. As shown

in Figure 1, the running drill was performed in an area of 20 m x 15 m on a natural grass pitch with four cones (A, B, C, D) marking each of the corners. A fifth cone (E) was placed at 10 m away from cone D along the line of cones B and D. The course was designed to incorporate the various sprint distance (10m – 25m) commonly found in football (Andrzejewski et al., 2013; Castagna et al., 2003; Spencer et al., 2005; Vigne et al., 2010; Wong & Wong, 2009). The start and end timing gates were set up at cone A, with the start gates set up in line with cones A, B and end gates in line with cones A, C. Timing gates were set up at the start and end of a 25 m straight line for the maximal velocity test and pace internalisation.

Participants were led through the course for familiarisation before the start of the test. They performed several trials of a 25 m straight line run at a target velocity (e.g. 30% of maximum velocity) for pace internalisation until two consecutive trials showed the velocity not exceeding 0.1m/s of the target velocity before attempting the running drill at the velocity. Verbal feedback was given to notify if the required velocity measured by the timing gates was higher or lower than what was achieved. GPS units were switched on before each trial and off after each running drill trial and verbal instructions for all movements were yelled out during each trial. The GPS unit were switched off after every trial to ensure that other movements such as moving around after the trial during rest will not affect the gathered results. GPS units were switched on for at least 1 minute before the commencement of each trial to ensure that the device was on full-recording mode. The time to complete the running drill for each velocity was measured by the timing gates. A rest period of 2 – 5 minutes was provided before the next running drill attempt. The same procedure was applied to the 60% of maximum velocity, followed by maximum effort. Resting periods between each trial was between 5 and 10 minutes according to the participant's preference.

The sequence of the running drill for each trial was as follow:

1. Run past the start timing gates (T) and cone A towards cone B
2. Make a 90° turn to the right to cone C
3. Make a 180° turn back to cone B
4. Make a half turn (approximately 45°) to the left towards cone E
5. Perform a jumping header at cone E and run towards cone D
6. Make a half turn to the left towards cone C
7. Make a half turn to the left towards cone A
8. Perform a jumping header at cone A and make a half turn to the left towards cone D
9. Make a 90 ° turn to the left towards cone C
10. Come to a complete stop at cone C and make a half turn to the left towards cone A
11. Run past cone A and the end timing gates to conclude the drill

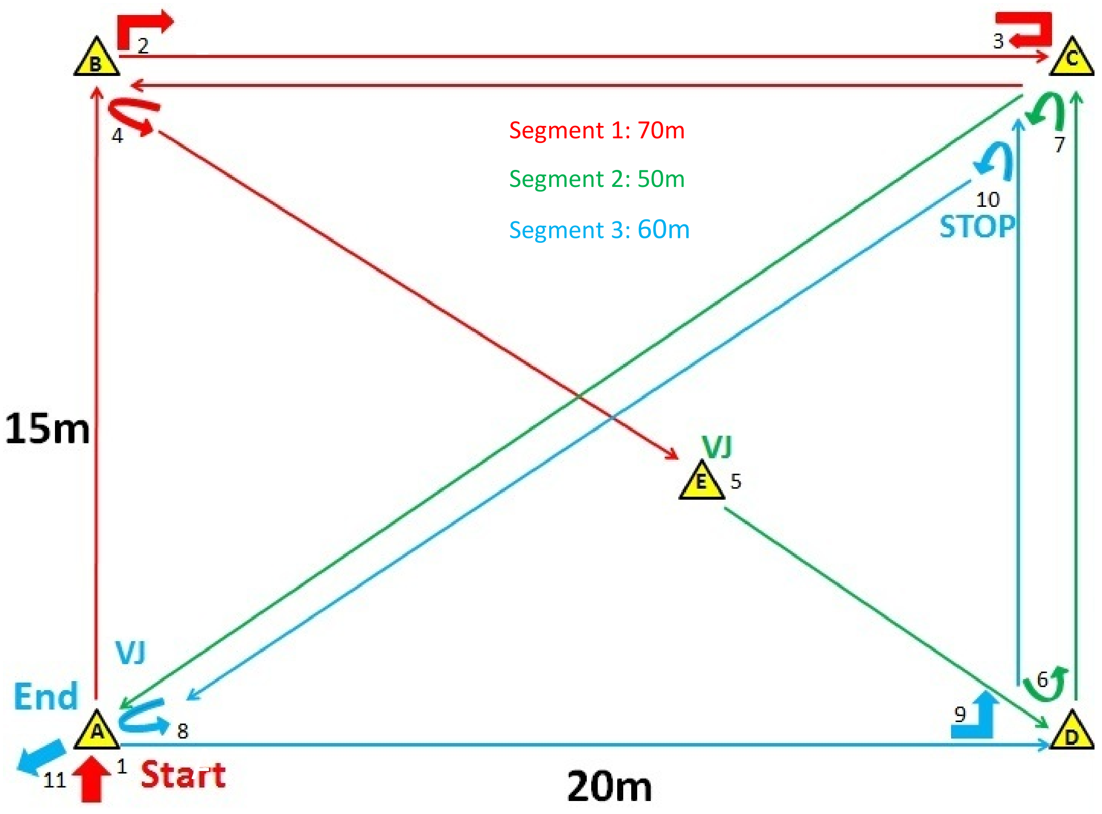

Figure 1: Running drill protocol within a 20 m x 15 m area with four cones (A, B, C, D) at each corner and cone E at 10m from the cone D. The drill includes change of directions (CoD), vertical jumps (VJ) and a complete stop. The sequence of movements is presented from numbers 1-11.The drill is separated into 3 segments using the start of each VJ as a splitting point. The distances of the segment 1, segment 2 and segment 3 are 70 m, 50 m and 60 m, respectively.

3.1.4 Data Acquisition and Analysis

A GPS device (GPSports SPI PRO X, Australia) was attached to the participant's upper back via a specially designed vest as shown in Figure 2. The device was switched on and attached to the participant immediately before the commencement of each running drill trial and switched off immediately after the participant came to a stop. Each participant used the same GPS unit for all trials over two sessions for data reliability (Coutts & Duffield, 2010). GPS derived data was downloaded to a computer via a data transfer dock and analysed using the manufacturer's accompanied software (Team AMS GPSports, Australia). The time

point of each jump of each trial was identified via accelerometer data of the vertical axis and recorded. Each trial was then split into 3 segments using the start of each jump as a separation point.

Figure 2: GPS placement at the upper back using a specially designed vest. Note: GPS placement demonstrated in the figure was intended for illustration purpose only, GPS devices were secured tightly in the pouch of the vest during all trials.

3.1.5 Body Load (BL)

BL data was extracted from the GPS and analysed using Team AMS (GPSports, Australia) software. Each trial was separated into 3 segments using the jumps as a split point; Start to Jump 1 (S-J1: Segment 1), Jump 1 to Jump 2 (J1-J2: Segment 2) and Jump 2 to End (J2-E: Segment 3). The time to complete each segment was calculated, and the total time to complete the running drill was obtained by adding the time for each segment.

BL of each segment was calculated using data gathered from an accelerometer sampling at 100 Hz imbedded within the GPS and was based on the following equation;

$$\sqrt{((ax_{t=i+1} - ax_{t=i})^2 + (ay_{t=i+1} - ay_{t=i})^2 + (az_{t=i+1} - az_{t=i})^2)} \,/\, 100$$

Where ax, ay and az representing the acceleration in the x, y and z axis, respectively, t represents time and *i* represents current time. BL of all 3 segments were added together to obtain the total BL for each trial.

3.1.6 Eccentric Index (EI)

The accelerometer data was extracted using Team AMS and sent to a private data analysis company (Athletic Data Innovations, Australia) for analysis of EI based on the equation in the same way as that for BL (i.e. three segments, total);

FL/ML*MW*scaling factor

Where Force Load (FL) is defined as the rate of g-force load during footstrike, Motion Load (ML) being the rate of movement load which is derived from the instantaneous velocity + body mass (BM) and Mechanical Work (MW) representing the rate of velocity change during acceleration, deceleration and changes of direction combined with a scaling factor based on body mass. EI is described as an index that represents the mean rate of eccentric loading of the recorded time duration. BM was recorded before the commencement of session 1 on a weighing scale (KC120s, Mettler-Toledo, USA).

3.1.7 Video Analysis

Two video cameras (Sony HD 1080i, Japan) were set up at the mid-point of cones AB and AC for further video analysis. Footage recorded by the video cameras was used to verify any abnormities in the BL and EI data collected. Further analysis of the video footage was performed to verify eccentric loading induced by each movement using Kinovea (Kinovea, France) by slowing the footage to frames of 0.16 second. Differences in knee bends were identified between velocities via visual inspection during 180° CoD, jump and stop.

3.1.8 Statistical Analysis

All statistical analyses were performed using a Statistical Package for the Social Sciences (SPSS) 19.0 (SPSS Inc, Chicago, IL, USA). Since no significant differences were found in terms of time to complete the four trials, the mean of the 4 trials collected for each velocity for each segment was used for further analyses. Comparisons for time, BL and EI of segments 1, 2 and 3 were made between each velocity (30, 60, and 100%) using One-way ANOVA. Comparison between each velocity (30, 60, and 100%) was made for time, BL and EI using one-way ANOVA. When a significant effect was detected, a Tukey posthoc test was administered to determine where the difference laid. A Pearson product-moment correlation was used to analyse the relationships between BL and EI, BL and the time to complete the running drill, and EI and time to complete the running drill. The alpha level was set at 0.05 for all statistical analyses.

3.2 STUDY 2

3.2.1 Participants

Ten state league level outfield players (defenders, midfielders and strikers) of a local football club, who were over 18 years of age, were recruited for this study. Their mean (±SD) age, height and body mass were 20.2 ± 4.0 years, 181.4 ± 4.4 cm and 78.6 ± 11.6 kg, respectively. The top ten players were selected by a coach based on their playing ability. However, due to some missing data points for muscle damage markers and GPS, only data from 6 players were used for the analyses. Permission to conduct the study was granted by the ECU Human Research Ethics Committee. The players completed a written informed consent consistent with the principles set out in the Declaration of Helsinki prior to participation in the

proposed study. They were asked to maintain their regular diet, and supplementation was not restricted, however they were requested to report if any supplements were taken. They were also asked to report if any medication or intervention such as massage was used within 24 hours after a training session.

3.2.2 Study Design

A total of four training sessions including one training game were monitored over 2 weeks in a playing season. The four training sessions were recorded using two video cameras (Sony HD 1080i, Japan) which were placed 20-m away from the touchline at the centre of the pitch to record the movements of the players. All players wore a GPS device (GPSports SPI PRO X, Australia) on their upper back in a specially designed vest (Figure 2) during the whole training session including warming up and cooling down periods. Muscle damage markers including the prolonged decrease in maximal voluntary isometric contraction of the quadriceps (Morton et al., 2005) and muscle soreness of the quadriceps and hamstrings, were measured before each training session and 24 hours after the session. Changes in these variables from before to 24 hours after the training session were compared across the four sessions. It was previously shown that possible indicators of muscle damage such as, the reduction of maximal voluntary isometric contraction torque of the quadriceps and delayed onset of muscle soreness were the highest 24 hours after a football match (Ascensão et al., 2010). Therefore, it was decided that a 24 hour post training measurement be taken to assess the magnitude of muscle damage sustained during training. Moreover, the decision also took into account of the team training schedule where only 2 days was available between training sessions in the weekdays.

3.2.3 Training Sessions

The team training sessions were conducted twice per week (Tuesday and Thursday) during the season with 2-3 days rest between sessions. The duration of each training session was 90-120 minutes including warm up and cool down. The content of each training session were determined by the coach and is presented in Table 1.

Table 1: Details of the activities performed in each training session.

Session 1	Session 2	Session 3	Session 4
30-15 Intermittent Fitness Test (20 min)	Friendly Match (90 min)	Repeated Sprints (10-50m) (20 min)	Attacking Build Up (Half Pitch) (15 min)
5 a side Small Sided Game (2 goals) (30 min)		Small Sided Game Half Pitch (25 min)	Defensive Ball Distribution (Half Pitch) (15 min)
Shooting Drill (5min)		Possession Half Pitch (25 min)	Full Pitch Training Game (30 min)
		Shooting Drill (10 min)	

3.2.4 Muscle Damage Markers

To assess muscle damage induced by the training, maximal voluntary isometric contraction (MVC) force of the knee extensors and muscle soreness of the quadriceps and hamstrings of the right leg were measured before and 24 hour after each training session (Morton et al., 2005).

3.2.4.1 Maximal Voluntary Contraction (MVC) Force

MVC force of the knee extensors of the right leg was measured using a strain gauge (Xtran Load Cell S1W, Applied Measurement Australia Pty Ltd, Melbourne, Australia)

attached to a wire with a belt surrounding the ankle joint of the player (Figure 3). The player sat on a custom designed chair with the knee joint angle adjusted to 70° (Peñailillo et al., 2013). The player attempted two submaximal trials before being instructed to extend the knee as quickly as possible and were asked to generate maximal force for 3 s (Thorlund et al., 2009). The maximal trial was repeated after a passive recovery of 60 s. The peak maximal voluntary contraction force was extracted from LabChart V7.3.5 Software (PowerLab System, ADInstruments, NSW, Australia). The higher torque of the two trials was used for further analysis. Comparisons of changes in MVC force before and 24 hours after each training session were represented as a percentage and used as an indirect marker of muscle damage.

Figure 3: MVC measurement protocol (left) and strain gauge placement (right)

3.2.4.2 Muscle Soreness

Using a visual analogue scale (VAS) consisting of a 10-cm straight line with the left end labelled as ‘no soreness’ and right end ‘maximum soreness’ (Miller & Ferris, 1993), players rated the soreness of their right quadriceps and right hamstrings after a quadriceps stretch and hamstring stretch, respectively. As shown in Figure 4, the quadriceps stretch was

performed by holding the right ankle at the position of the right gluteus for 5 seconds, and the hamstring stretch was performed by placing the right ankle on a 60-cm platform and a deliberately flexing of the hip towards the outstretched knee**.** Players were asked to indicate their level of muscle soreness by marking their perceived pain level on the VAS, which had a sensitivity of one millimetre.

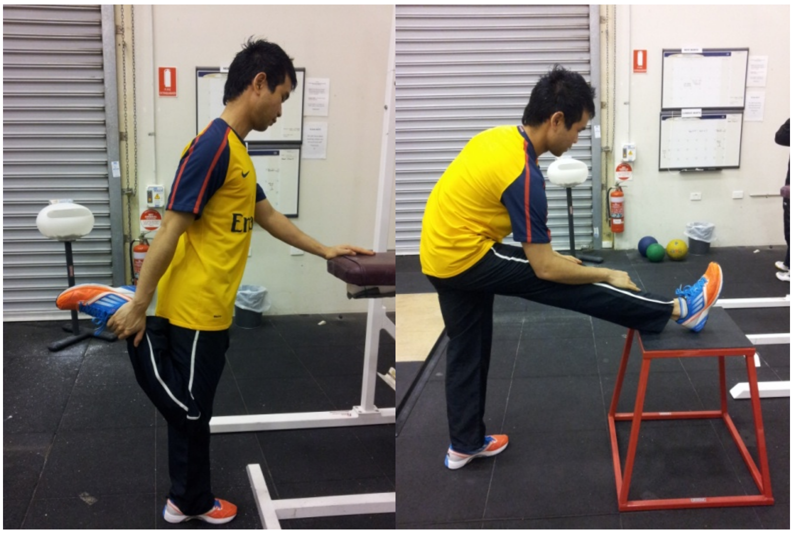

Figure 4: Quadriceps stretch (left) and hamstrings stretch (right)

3.2.5 Body Load (BL) and Eccentric Index (EI)

GPS units were switched on at the same time and attached to each player before the commencement of each training session. To prevent confounding effects from inter-unit variability, each player was assigned to the same GPS unit for the four training sessions (Coutts & Duffield, 2010). Time point splits were set at the start of each training session and at the end of the training session to ensure only activities within the training sessions were considered. BL of each session was derived by the calculation generated by Team AMS. A GPS derived data file was extracted using Team AMS software and sent to Athletic Data Innovations for analysis of EI.

3.2.6 Video Analysis

Video footage collected from the training sessions were used to verify the contents of each training session and to visually detect any abnormities in the BL and EI data. Further analysis of the video footage was performed to identify the number of CoDs performed in session 2. Video analysis was performed for a selected 5 minutes duration recorded during session 2 (friendly match). The total number of CoD performed during the period was coded for each player and recorded. CoD was defined as a quick switch in the previous headed direction with an idle period of <1s.

3.2.7 Statistical Analysis

All statistical analyses were performed using the software package Statistical Package for the Social Sciences (SPSS) version 19.0 (SPSS Inc, Chicago, IL, USA). A paired t-test was used to determine the changes in measures between pre-training and post-training at 24 h for MVC force and muscle soreness of the quadriceps and hamstrings. A one-way ANOVA was used to compare BL and EI across the four training sessions. When a significant main effect was detected, a Tukey posthoc test was administered to find where the difference laid. A Pearson product-moment correlation was used to analyse the relationships between GPS derived variables (BL, EI) and the magnitude of change in MVC force and muscle soreness from pre- to post-training. The alpha level was set at 0.05 for all statistical analyses.

CHAPTER 4

4. RESULTS

4.1 STUDY 1

Each participant performed 4 trials for each velocity over two separate days (2 trials/day). Although some differences existed between trials, the mean of 11 participants did not show any significant difference across the 4 trials for any variables. Thus, the mean of the 4 trials of 11 participants is presented below for each variable.

4.1.1 Time to Complete the Running Drill

The time to complete the drill was 102.9 ± 15.2 s for 30%, 56.3 ± 5.6 s for 60%, and 42.6 ± 3.1 s for maximum (100%) velocity, with each significantly ($p<0.05$) different from the others (Figure 5). The magnitude of the difference in the time between 60% and maximum velocities was only 7%, but that between 30% and 60% velocities was 45%.

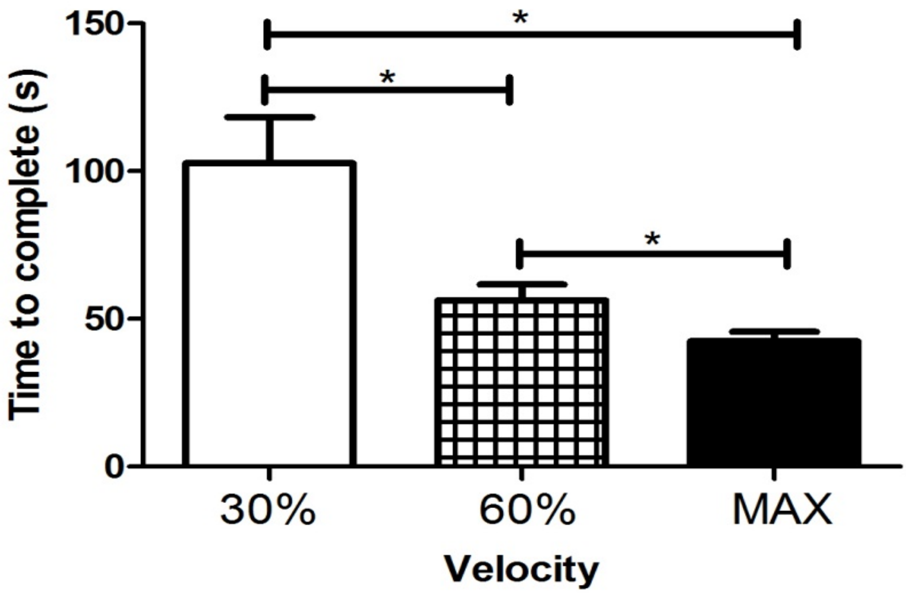

Figure 5: Comparison between the time to complete the running drill (mean ± SD, n=11) between three different velocities (30%, 60%, and maximal). *: Significant ($p<0.05$) difference between velocities.

The time to complete each segment is compared for each velocity in Figure 6. A significant ($p<0.05$) difference was found between segments 1 (70 m) and 2 (50 m) for 30% only, and segments 2 (50 m) and 3 (60 m) for 30%, 60% and maximal velocities.

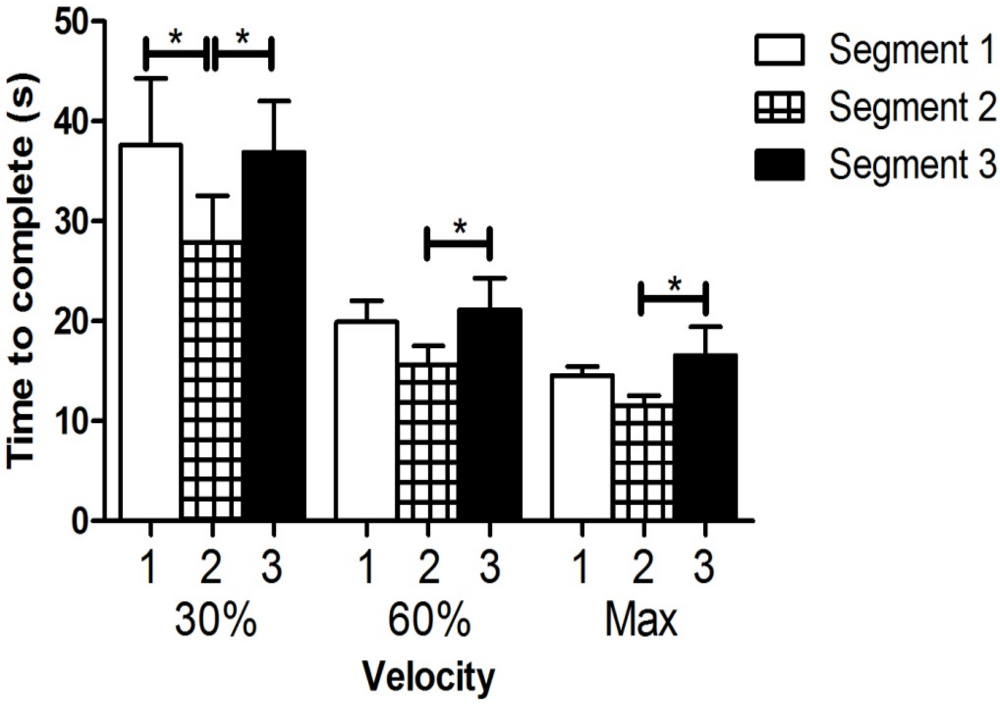

Figure 6: Comparison of the time (mean ± SD, n=11) to complete each segment (1, 2, and 3) at three different velocities (30%, 60%, and maximal). *: Significant (p<0.05) difference between segments.

4.1.2 Body Load (BL)

When comparing BL during the running drill between the three different velocities with segments 1, 2 and 3 combined, a significant difference (P<0.05) was found between 30% and maximal, but not between 30% and 60%, and 60% and maximal velocities (Figure 7). For the mean values, BL during 60% velocity (14.3 AU) was approximately 2 times of that during 30% velocity (8.3 AU), BL at maximal velocity (17.2 AU) was only 0.2 times that at 60%.

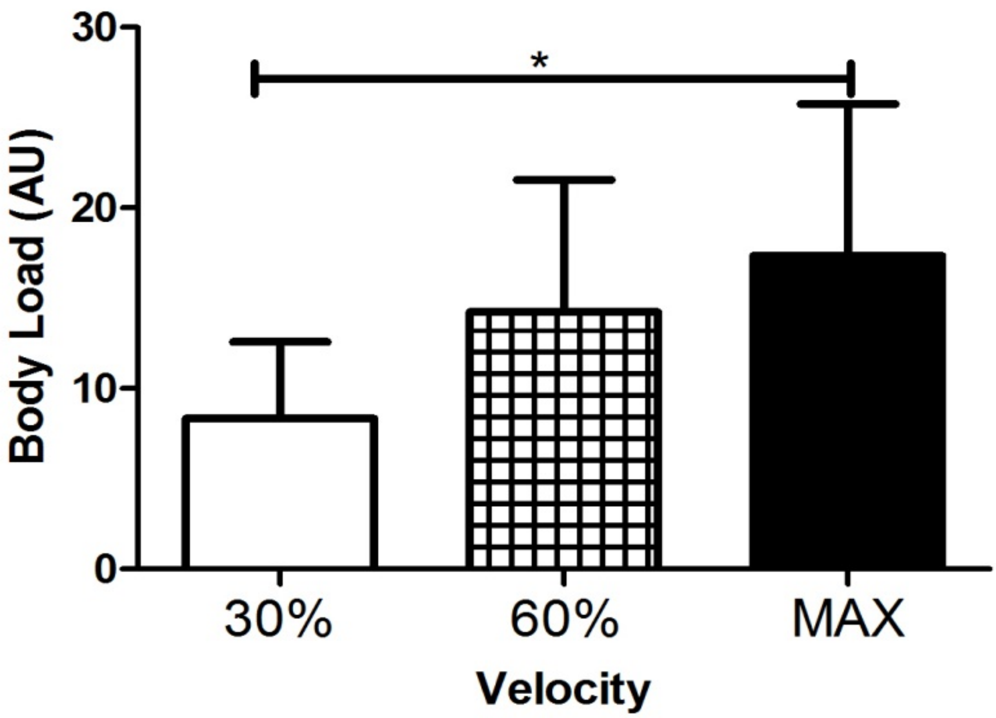

Figure 7: Comparison of the body load (mean ± SD, n=11) during the running drill between three different velocities (30%, 60%, and maximal). *: Significant ($p<0.05$) difference between velocities. Note: Segments 1, 2 and 3 are combined for each velocity.

BL of the 1st, 2nd and 3rd segment was 3.1 ± 1.6, 2.4 ± 1.1 and 2.8 ± 1.5, respectively for 30%, 5.3 ± 2.9, 4.1 ± 2.2 and 4.9 ± 2.4, respectively for 60%, and 6.5 ± 3.3, 4.6 ± 2.3 and 6.3 ± 2.9, respectively for maximum velocity. No significant differences were found between segments for each velocity (Figure 8).

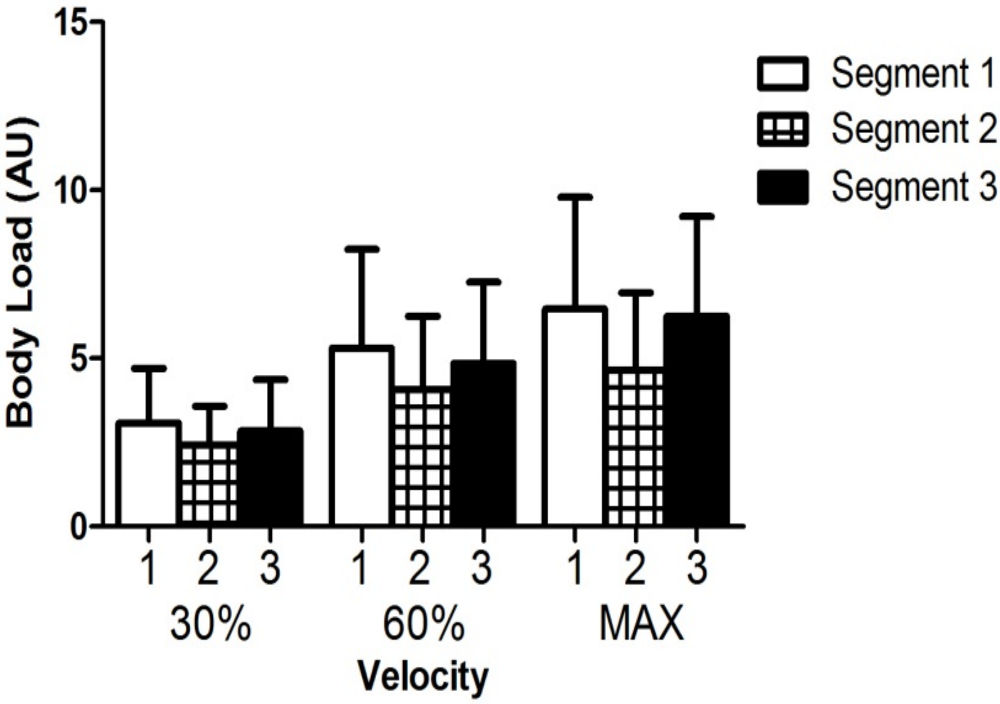

Figure 8: Comparison in the body load (mean ± SD, n=11) between segments (1, 2, and 3) of the running drill for each velocity (30%, 60%, and maximal).

4.1.3 Eccentric Index (EI)

EI was adjusted by the time taken to complete the running drill at each velocity, since the raw values were based on the time taken to complete the drill, and a significant difference existed for the time between velocities as shown in above (Figure 5). Thus, the EI value of each subject for each trial was multiplied by the time taken to complete the drill, and a normalised EI per minute was obtained. This was also the case for the EI of each segment. For example, an EI of segment 1 was 23.6, and the time to complete the first segment was 87.8 s, the normalised EI for the segment was 11.0.

The normalised EI of the whole drill is compared between the three velocities in Figure 9. Significant ($P<0.05$) differences were found between 30% and 60%, 30% and maximal, and 60% and maximal velocities (Figure 9).

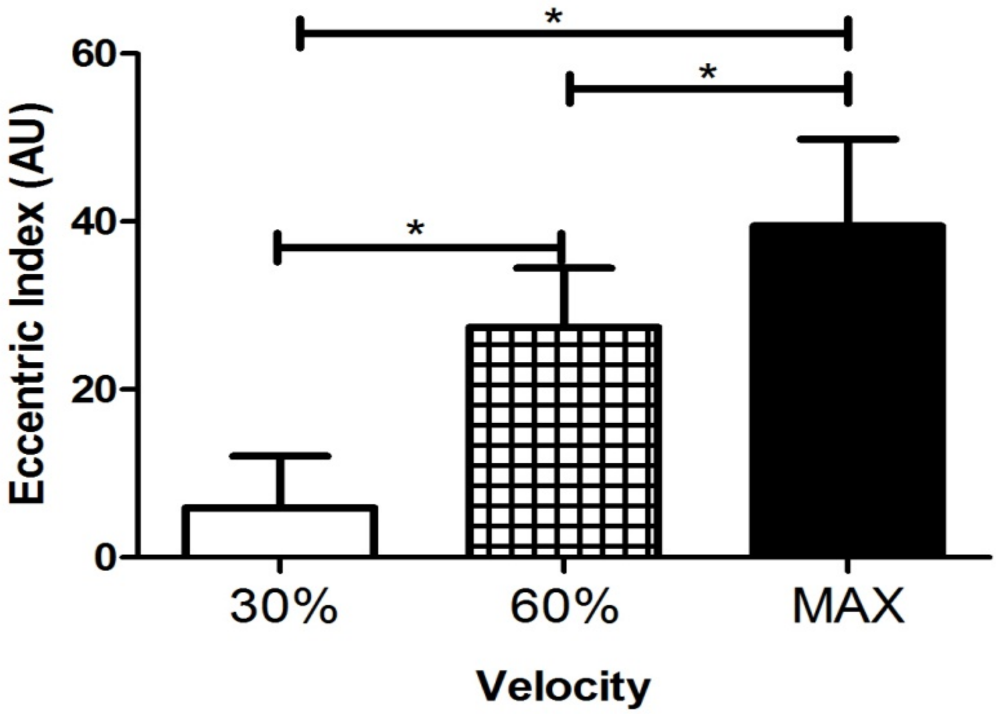

Figure 9: Comparison of EI (mean ± SD, n=11) for the running drill between three different velocities (30%, 60%, maximal). *: Significant ($p<0.05$) difference between velocities.

The normalised EI for the 1st, 2nd and 3rd segment was 2.5 ± 3.3, 2.4 ± 1.1 and 2.8 ± 1.5, respectively for 30%, 13.3 ± 4.9, 4.8 ± 2.3 and 9.3 ± 2.7 for 60%, and 14 ± 4.9, 10.3 ± 4.1 and 15.2 ± 4.8 for 100%. No significant difference among the segments was found for 30%, however, the EI of segment 2 was significantly smaller than that of segment 1 for 60%, and the EI of segment 2 was significantly smaller than that of segment 3 for maximal velocity (Figure 10).

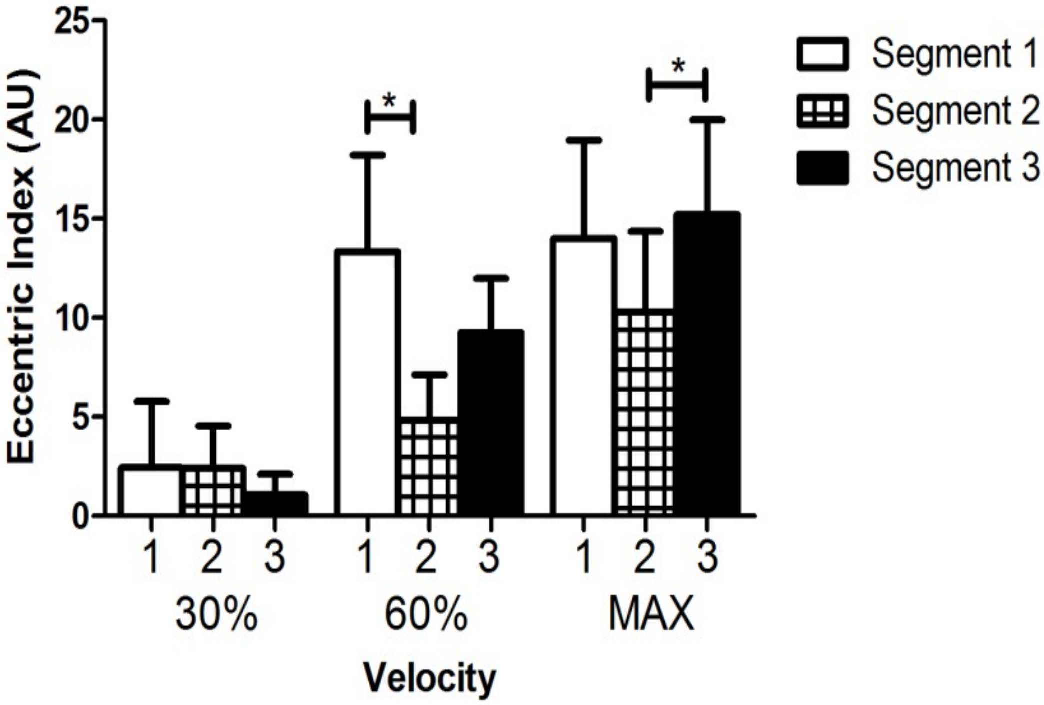

Figure 10: Comparison of the eccentric index (mean ± SD, n=11) between segments (1, 2, and 3) of the running drill for each velocity (30%, 60%, and maximal). *: Significant ($p<0.05$) difference between segments.

4.1.4 Relationships Between Variables

When comparing the time to complete the running drill and BL at 30%, 60% and maximal velocity, no significant relationships were found for all velocities (Figure 11).

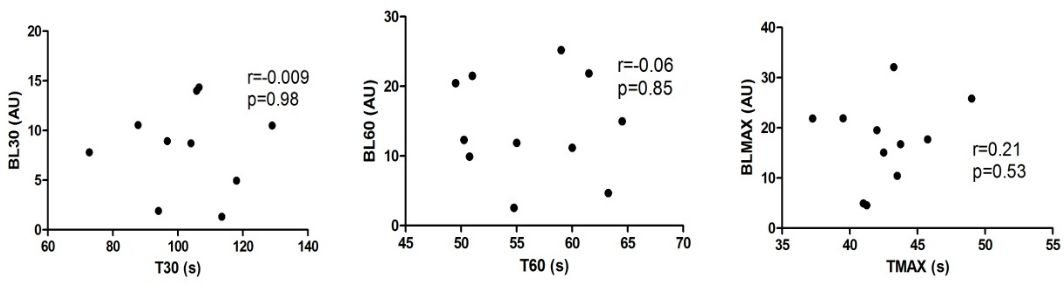

Figure 11: Correlation between the time to complete the running drill (T) and body load (BL) for 30% (left), 60% (center), maximal (right) velocities (n=11).

A significant negative correlation (r=-0.75) was found between the time to complete the running drill and EI at 30%; however, no significant correlations were found between 60% and maximal velocities (Figure 12). It was observed that there seem to be a trend in correlation for 60% that is just short of being significant (Figure 12).

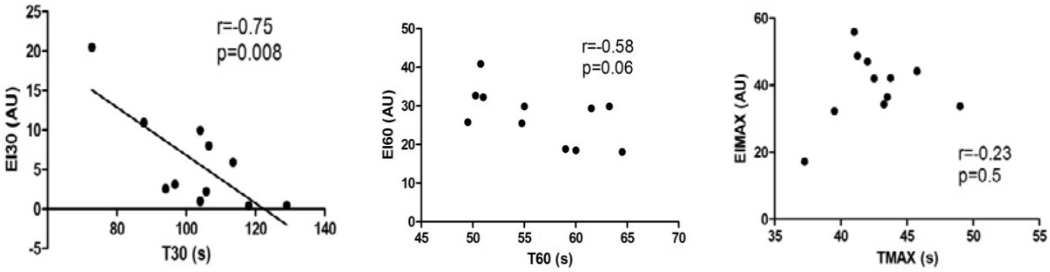

Figure 12: Correlation between the time to complete (T) and eccentric index (EI) for 30% (left), 60% (center) and maximal (right) velocities (n=11).

Figure 13 shows the relationship between BL and EI for each of the three different velocities (30%, 60%, maximal). A significant (P<0.05) negative correlation was found between BL and EI for maximal velocity, but no significant correlation was found for other velocities.

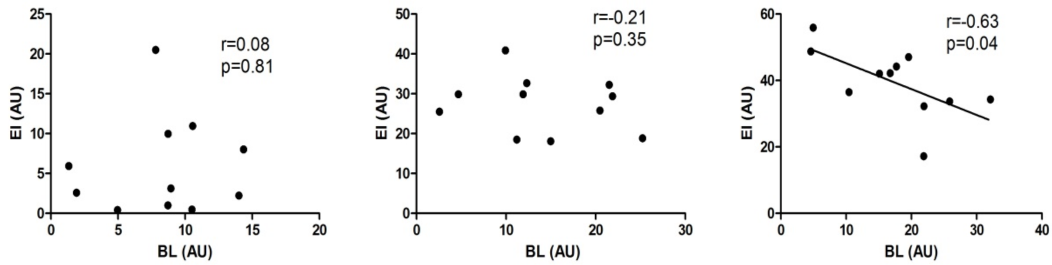

Figure 13: Correlation between body load (BL) and eccentric index (EI) for 30% (left), 60% (centre) and maximal (right) velocities (n=11).

4.1.5 Video Analysis

Video recordings were analysed to identify eccentric phases in the movements during the running drills. The picture frames provided below show typical examples of 180° change

of direction (Figure 14), jump (Figure 15) and stop (Figure 16). Through visual inspection, differences in knee bends were noted between velocities.

As shown in Figure 14, the knee joint at the turn was bent more at 60% (picture 3) than 30% (picture 4), and maximal (picture 3) than 60% velocity (picture 3). However, no distinct difference in the knee joint angle was observed for the jump between 30% (picture 6), 60% (picture 6) and maximal (picture 6) velocities (Figure 15). For a complete stop, a greater knee bend was observed for maximal (picture 4) followed by 60% (picture 3), and least for 30% (picture 4) velocity (Figure 16). An exaggerated upper trunk movement was also observed at higher velocities during a 180° turn (Figure 14, picture 2-4) and complete stop (Figure 16, picture 2-4).

Figure 14: Movements for 180° turn at 30%, 60% and maximal velocity running drills. The sequence is shown by the numbers (from 1-8, or 1-6).

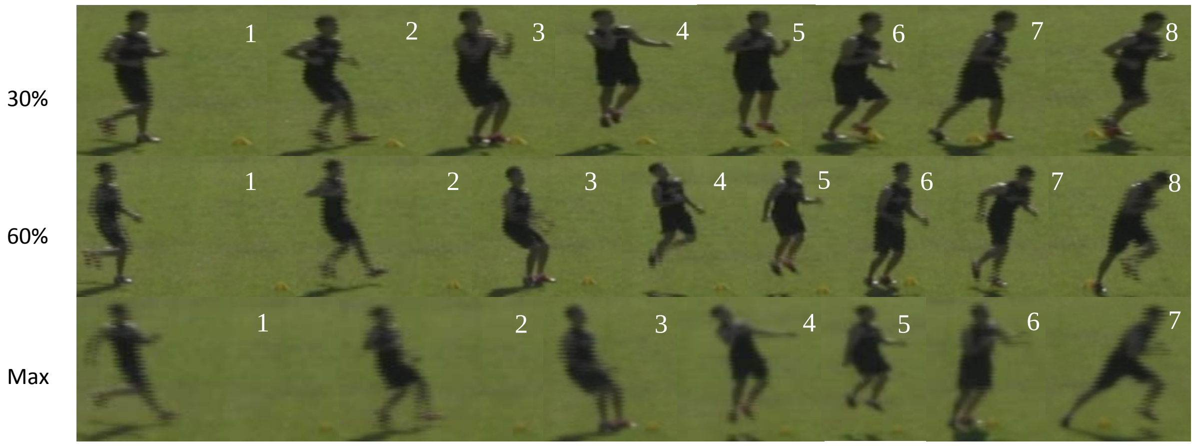

Figure 15: Movements for jump at 30%, 60% and maximal velocity running drills. The sequence is shown by the numbers (from 1-8, or 1-7).

Figure 16: Movements for complete stop at 30%, 60% and maximal velocity running drills. The sequence is shown by the numbers (from 1-7, or 1-6).

4.2 STUDY 2

Due to some missing data points for muscle damage markers of 4 players, the analyses were based on 6 out of the 10 players. Muscle damage markers were not collected for 4 of the 10 players recruited due to their absence during the post-training testing session.

4.2.1 Body Load (BL) and Eccentric Index (EI) During Training Session

The values of BL were obtained from the total recording time of each training session (90 – 120 minutes). EI of each session was represented as a mean rate of the recorded session.

No significant changes in BL (Figure 17) were found between the 4 training sessions. EI in session 1 was significantly greater than EI in sessions 2 and 3 (Figure 18). The mean (± SD) BL and EI over the four sessions were 458 ± 131 AU and 17.4 ± 5.7 AU, respectively.

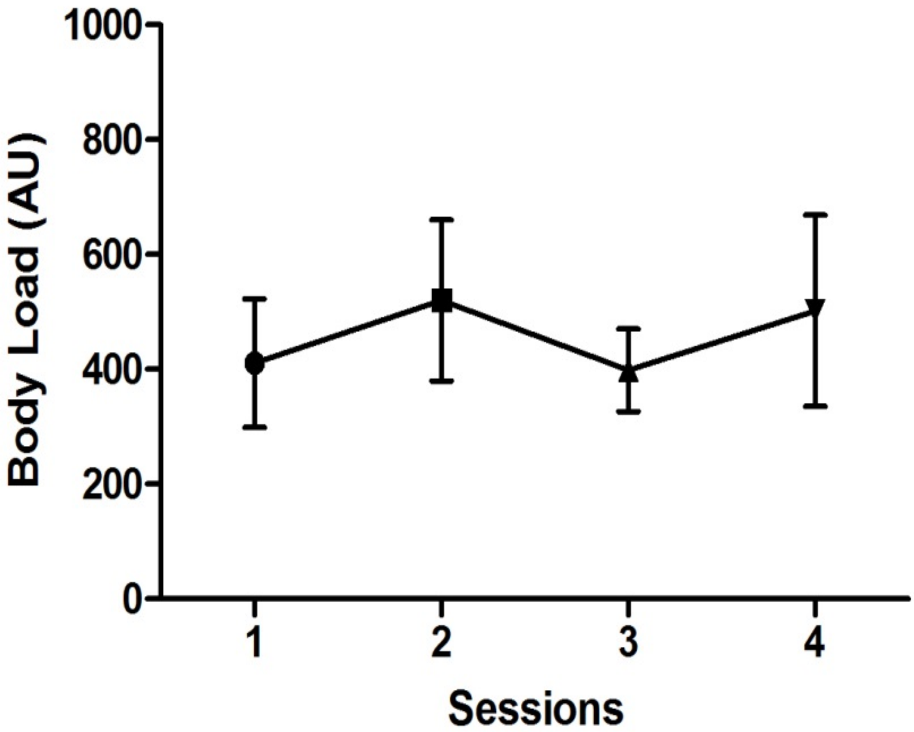

Figure 17: Body load (mean ± SD, n=6) over four training sessions (1-4).

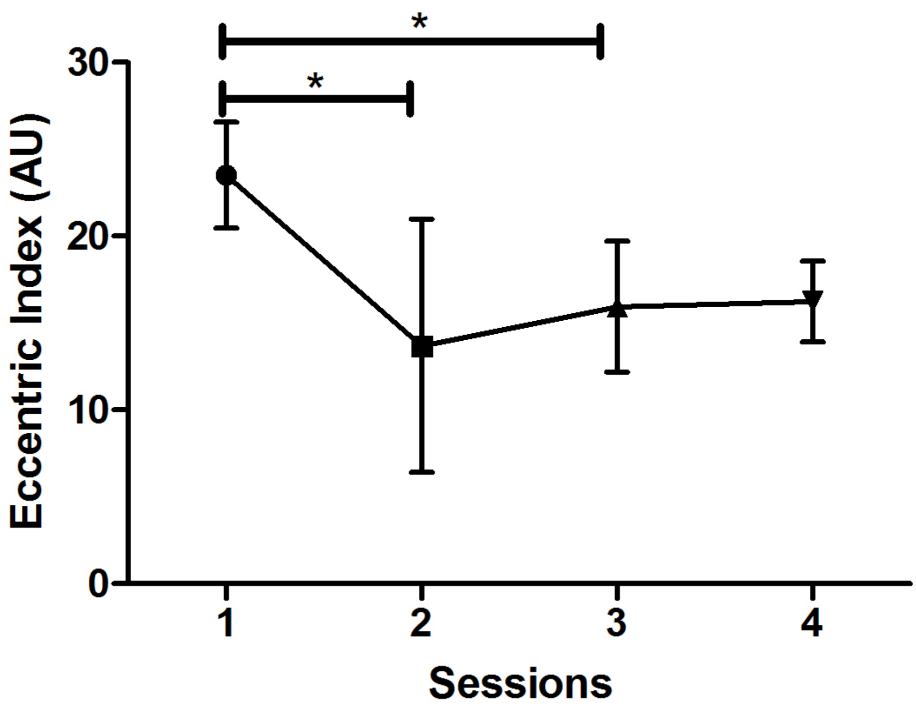

Figure 18: Eccentric Index (mean ± SD, n=6) over four training sessions (1-4). *: Significant ($p<0.05$) difference between sessions.

A larger variability in EI was observed for training session 2 which included a friendly match between the home team and an opposing team from a lower league. In Table 3, the data of 6 players are shown. It appears that the variation of BL and EI was due to the high load sustained by one central midfielder. Players with a high EI performed a greater number of changes of direction (CoD) when compared with the players with lower EI. Players who had a high mechanical work, a measure representing the total accumulation of CoD, accelerations and decelerations and low percentage of the total distance above 16km/h, were found to have high EIs.

Table 2: Position, body mass, body load (BL), total force load, total mechanical work, total motion load, mean rate of eccentric index (EI) of the duration of the match, percentage of the distance covered with the velocity greater than16 km/h (% Total Distance > 16 km/h), the total distance covered (Total Distance) and number of change of directions for 5 minutes during the game (CoD) of each player in training session 2.

Player	Position	Mass (kg)	BL (AU)	Force Load (AU)	Mechanical Work (AU)	Motion Load (AU)	EI (AU)	% Total Distance > 16 km/h	Total Distance (m)	Number of CoD
1	Right Back	75.8	388	848	9.0	489.1	9.7	11.5	6303	14
2	Forward	69.7	533	958	10.3	617.5	10.0	16.3	8686	14
3	Centre Midfield	75.1	785	1800	12.0	470.6	28.3	2.2	8155	29
4	Left Back	76.1	439	1071	13.6	761.9	11.9	13.8	9696	13
5	Centre Back	101.7	516	1859	8.0	728.1	12.7	7.1	8060	12
6	Defensive Midfield	73.0	459	1191	7.2	552.9	9.6	8.1	7098	15

4.2.2 Muscle Damage Markers

Changes in markers of muscle damage (MVC force, and muscle soreness) before and 24 h after training session 2 in which a friendly match was performed are shown in Figures 19 and 20. No significant changes were found from pre- to post-training session for MVC strength (Figure 19) and muscle soreness represented by VAS for the quadriceps and hamstrings (Figure 20).

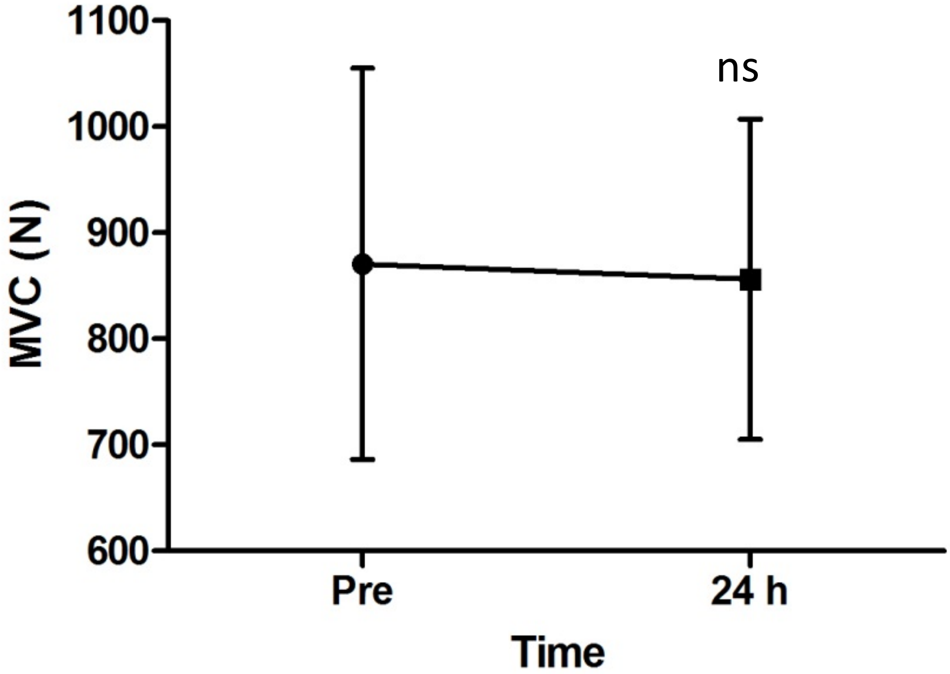

Figure 19: Changes (mean ± SD, n=6) in maximal voluntary contraction force (MVC) before (pre) and 24 h after a training session. ns: not significantly different from pre-training value.

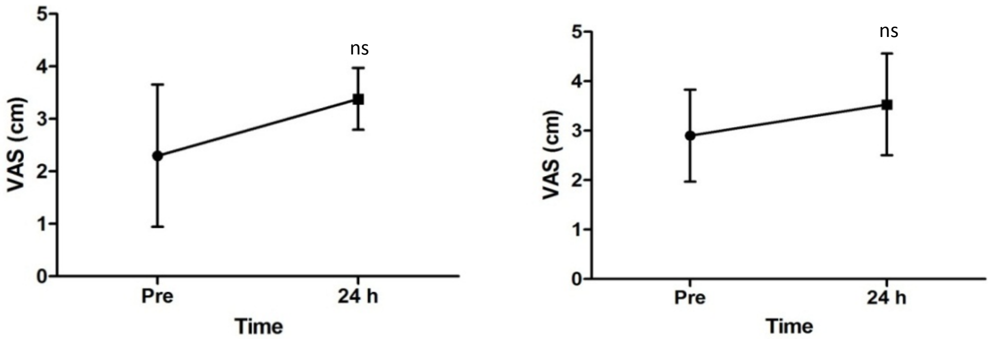

Figure 20: Changes (mean ± SD, n=6) in muscle soreness of quadriceps (left) and hamstrings (right) assessed by a 10-cm visual analogue scale before (pre) and 24 h after training session 2. ns: not significantly different from pre-training value.

4.2.3 Relationships Between Variables

MVC force changes were calculated by the magnitude of change (percentage) from pre- to post-training session, and changes in muscle soreness was presented as the difference in a VAS between post- and pre-training values. No significant correlation ($p<0.05$) was found between VAS of the hamstrings or quadriceps and BL (r=-0.89, r=-0.1), as well as EI (r=0.54, r=0.11), No significant correlations were found between MVC change and BL (r=0.12), MVC change and EI (r=0.27), muscle soreness change in the hamstrings or quadriceps and BL (r=-0.79, r=-0.35), and muscle soreness change in the hamstrings or quadriceps and EI (r=-0.75, r=-0.17). There are also no significant relationship was found between BL and EI (r=-0.25) after a training match.

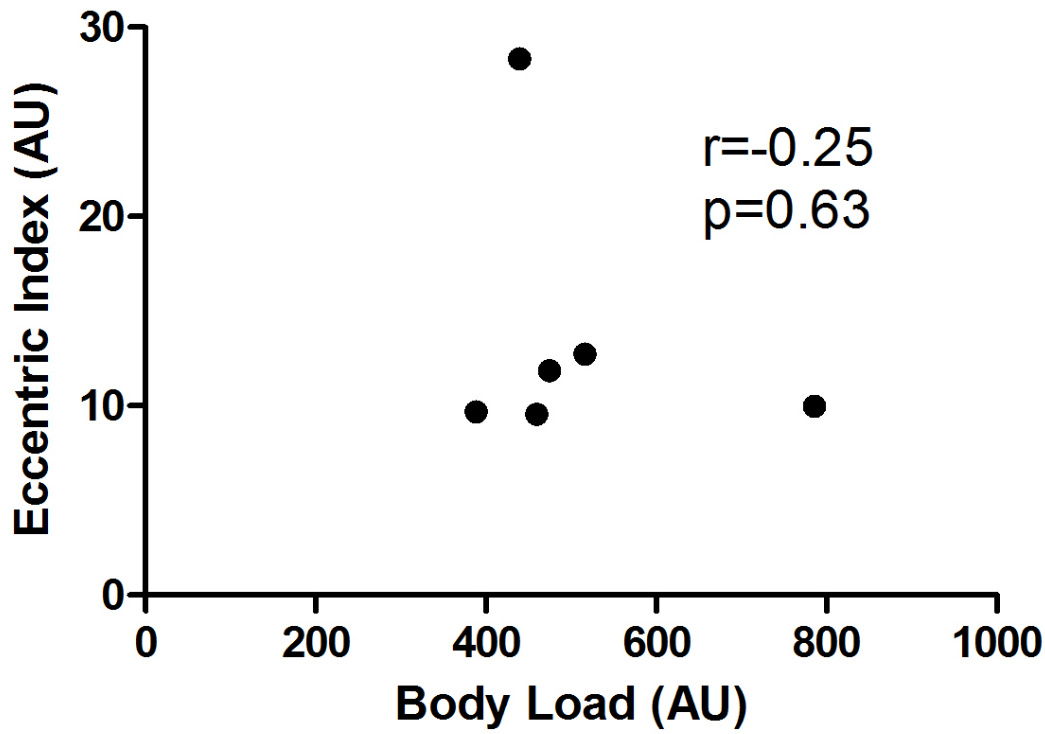

Figure 21: Correlation between eccentric index (EI) and body load (BL) for session 2 (n=6).

CHAPTER 5

5. DISCUSSION

5.1 Study 1

The purpose of Study 1 was to test the hypotheses; 1) that BL would not fully represent eccentric load, but 2) EI might represent eccentric load better than BL, during a running drill consisting of changes of directions (CoD), a jump and a complete stop, performed at three different intensities (30%, 60% and maximal velocities). It was assumed that eccentric loading would increase with the increase in the running velocities due to the larger decelerations incurred when stopping or changing direction. The results showed, 1) there were no significant differences in BL between velocities (30% - 60%, 60% - max), 2) there were significant differences in EI between velocities (30% - 60%, 60% - max) reflected by EI, 3) there were no significant differences in BL between segments (segments 1, 2, and 3) within each velocity (30%, 60%, and max), 4) there were significant differences in EI between segments 1 and 2 at 60% and segments 2 and 3 at maximum velocity, and 5) there was no significant positive relationship between BL and EI. In short, these results appear to support the hypotheses put forward.

The running drill was designed to reflect movements in non-contact team sports such as CoD, jumps and stops which are deemed to be important for achieving success in a game (Varley et al., 2012; Vigne et al., 2010), and movement distances that are commonly found for sprints (10m – 25m) in football (Andrzejewski et al., 2013; Castagna et al., 2003; Vigne et al., 2010). The velocities were chosen with the intention of increasing eccentric loading from 30% through to maximal velocity. It was observed that the difference in the time to complete the running drill was only 7% between 60% and maximal velocities, although the difference in the time to complete between 30% and 60% velocities was 45% (Figure 5). The small

difference in the time between 60% and maximal velocities may be due to the participants being unable to maintain maximum velocity throughout the entire running drill (180 m) despite receiving strong verbal encouragement form the investigator. However, it appears that the eccentric loading was increased with increasing running velocity from 30% to 60%, and 60% to maximal velocity as shown by video analysis (Figures 14-16). The video analysis showed that a greater bend in the knee joint was present in 60% and maximum trials during a 180° turn and complete stop when compared to 30%. However, greater excursions of the upper trunk were also present with the increasing velocities.

The 180-m running was divided into three segments of similar distance (segment 1: 70 m, segment 2: 50 m, segment 3: 60 m) but comprising different movements. It was assumed that segment 3 including one jump, two half turns, one 90° turn and one complete stop, would result in the greatest eccentric loading followed by segment 1 (one 90° turn, one 180° turn and one half turn) then segment 2 (one jump and two half turns), since previous research has shown large eccentric muscle activity when performing jumps (especially landing), complete stops and a turns (Fagenbaum & Darling, 2003; Nyland et al., 1994; Rand & Ohtsuki, 2000). The video analysis showed that the knee joint of the leg absorbing force bent more with increasing velocity for 180° turns (Figure 14) and complete stops (Figure 16), but this was not the case after jumps (Figure 15). It is assumed that the increase in knee bend indicates an increased eccentric loading to the quadriceps and hamstrings to decelerate the forward momentum of the body.

Hewitt et al. (2011) stated that the primary objective in deceleration was to decrease the body's momentum (mass x velocity) by applying as much force as possible over the shortest amount of time to come to a complete stop or direct the movement to a new direction (force x time = mass x velocity). If there is an increase in velocity, a higher force is required

to decelerate in the same time. It was previously assumed that a jump induced a high eccentric load, however, the jump performed in the running drill was considered a vertical-stop jump rather than a conventional vertical jump as the participant was more concerned in moving forward than performing a traditional full landing (Figure 15). Fagenbaum and Darling (2003) showed that knee flexion angle upon landing was smaller when jumping 25 cm to the front (45°) when compared to a vertical jump (60°). Chappell et al. (2007) compared knee kinematics of male and females to investigate the risk for non-contact anterior cruciate ligament injury and reported that male subjects landed a vertical-stop jump at a knee flexion of 24°. It can be observed from both studies that jumps other than a conventional vertical jump with a standing start will result in a smaller knee flexion. Therefore, it does not appear that the jumps in the running drill in the present study required a large eccentric loading. This might explain why segment 3, previously hypothesized to cause the most eccentric loading, did not induce significant eccentric loading compared to segment 1.

Based on the equation of BL, it was assumed that it would include all movements, both eccentric and concentric. Hence, it was hypothesised that BL would not be a good indicator of eccentric load. Scott et al. (2013) used GPS to monitor 15 professional football players competing in the Australian professional league (A-league) to estimate their external training load, and showed that BL was highly correlated (r=0.93) with the total distance travelled in a football game. In the present study, BL was greater in absolute values for segment 1 (70 m) followed by segment 3 (60 m) and segment 2 (50 m,) for all velocities (Figure 8). It should be noted that no significant differences were evident in BL between 30% and 60%, and 60% and maximal velocities (Figure 7). This also suggests that BL is not reflective of the increased eccentric loading induced by the increase in velocity. Therefore, it would appear that BL is not a sensitive measure of eccentric load.

The EI is derived from 3 main components, 1) the Force Load (FL), a measurement of the accumulated forces derived from footstrikes, 2) Motion Load (ML), a measure which represents the a large accumulation of time in high velocity and 3) Mechanical Work (MW), the accumulation of CoD, accelerations and decelerations. The developer of EI explained that EI was developed on the basis that a session that consists of a high FL, a low ML and a high MW with induce a high magnitude of eccentric load. A session in this manner is thought to represent a high total number of steps taken, high number of start-stop at high velocity and a high frequency of CoD, accelerations and decelerations, and this combination is believed to induce a high amount of eccentric load (personal communication with developer, 2013). The EI is usually presented as an average rate measurement based on the duration of the session recorded. Coaches utilising the EI will compare the EI figures amongst players performing the same training session to identify the players with high EI who might be at greater risk of sustaining an injury or decrements in performance. This differs from BL that is normally displayed as the total accumulation of load of a session. Thus, it is illogical to compare a rate measure with a volume measure. Hence, the EI data presented in this study was multiplied by the total duration of the session recorded to obtain a volume measure, which resulted in a similar metric similar to BL (Table 2). Significant differences in this measure of EI between velocities were observed (Figure 9), showing that the higher the velocity, the greater the EI. For the comparison between segments, a significant difference in EI was found between segments 1 and 2 at 60%, and between segments 2 and 3 at max (Figure 10). As shown in the video analysis, it seems likely that eccentric loading during CoD and the stop increased with increasing the velocity (Figures 14 & 16). Thus, it appears that EI represents eccentric loading better than BL.

It is interesting to note that BL and EI were negatively correlated for maximum velocity, but there was no significant correlation was evident for 30% and 60% (Figure 13). Even though the result should be viewed with caution due to the small sample size (n=6), this suggests that BL and EI are inherently different measures. BL is reported as the accumulation of load gathered in all 3 axes, including the frontal and sagittal planes while EI may take into consideration of the vertical plane alone. As the GPS unit was attached to the participant's upper back, BL might have been affected by the additional upper trunk motions during the exaggerated movements in the turns. In fact, it was observed that there were greater excursions of the upper trunk, where the GPS unit was located during CoD and coming to a complete stop at 60% and maximum velocity. This was previously noted by Netto et al. (2010) who compared the acceleration data gathered from a GPS unit attached to the upper back of a participant with motion analysis data gathered using a 24-camera high speed motion analysis system during a multiple running and cutting task. It was found that the peak acceleration data of both the running and cutting tasks were significantly higher compared to the motion analysis data. They concluded that the current placement of GPS units at the upper back or the base of the neck does not provide an accurate measure of vertical and vector magnitude load during running and cutting movements, possibly due to the distance of the accelerometer from the impact site and the vibration of the unit within the harness (Netto et al., 2010). It may be that since EI considers the vertical plane alone, EI was less affected by the additional upper trunk movements compared to BL.

In summary, the findings showed that BL and EI appear to be measuring different variables. EI was shown to be a better indicator of the increasing eccentric load induced by the variation of movements and increasing velocity in a controlled running drill environment compared to BL. It was also shown that BL of each segment might be related to the total

distance of each segment, similar to what has reported in previous research. However, the current position of the GPS unit at the upper back might pose a problem in accurately measuring the magnitude of eccentric load of the lower body. It should be noted that from the author's knowledge, the current study is the only study that dealt with EI. Unfortunately, due to the large variability of the running drill design, an accurate repeatability measure cannot be determined. However, this can be further investigated by future studies. In hindsight, a validation study of EI against eccentric loading should have been conducted to further the understanding of EI as a measurement of eccentric loading before attempting to validate its accuracy as a field-based measurement of eccentric load.

5.2 Study 2

The purpose of Study 2 was to investigate changes in BL and EI over four training sessions of football, and examine whether BL and EI are associated with changes in knee extensor strength and muscle soreness of thigh muscles from before to one day following a training session. As Study 1 was limited to a total distance of 180 m, lasting a short duration of no more than 2 minutes, Study 2 was designed to provide an exercise session closer to the actual application of monitoring eccentric load in the "real world". It was hypothesised that EI would be able to indicate the magnitude of eccentric loading and muscle damage after a training session. The results showed 1) no significant differences in BL between the 4 training sessions, 2) EI of session 1 was significantly greater than that of sessions 2 and 3, 3) no significant correlation between BL and markers of muscle damage (MVC force and muscle soreness) in session 2 (training game), and 4) no significant correlation between EI and markers of muscle damage in session 2. In summary, the results did not support the hypotheses.

The limitation of this study was that only 6 players were effectively monitored, although it was planned to monitor 10 players throughout the training sessions to represent the number of outfield players of one team in a football match. This was due to the non-compliance of the 4 players during testing sessions for the 24h post-training. Thus, the sample size might not be sufficient to justify any findings arising from this specific study. However, mean BL data gathered from all 4 training sessions (458 AU) seemed to be comparable to the BL of a typical football training session as detailed by Scott et al. (2013) who monitored PL (558 AU) of 15 professional football players in training sessions lasting 60 – 90 minutes. Thus, it can be assumed that the intensity of the training session is comparable to a professional training session.

There were some differences in the content among the four training sessions (Table 1), but no significant differences in BL (Figure 17) were found. However, EI of session 1 was significantly greater than session 2 and 3 (Figure 18). The finding should be viewed with caution as a potential in regards of the eccentric loading induced in the sessions and the application of EI due to the limited number of training sessions monitored. Session 1 contained a 30-15 intermittent fitness test (Table 1) which required the players to perform CoD at high velocities in the latter section of the test, which might explain the high EI compared with other sessions. Varley and Aughey (2013) reported that at the same level of play, a less successful team was found to perform more high-velocity running compared to a more successful or higher ranked team. Therefore, it is possible that the low EI found in session 2 (training game) was due to the lower playing standard of the opposing team.

It was observed that a large standard deviation of EI was present in session 2, hence further investigation was conducted to inspect individual players (Table 2). It was observed that player 3, who was the only central midfielder in the team, had the highest BL and EI

among the 6 players. Burgess et al. (2006) analysed game performance of 45 male professional football players (15 defenders, 15 midfielders, 15 forwards) for movement profiles in each of the games played, and reported that midfield players participated in more events (kicking, heading and tackling) compared with other positions. In fact, the video analysis from the current study demonstrated that player 3 performed the largest number of CoD within the span of 5 mins compared with the other players (Table 3). The player also showed high mechanical work (accumulation of CoD, accelerations and decelerations) but a low percentage of the total distance travelled at greater than 16km/h and low ML (representing a less continuous duration at high velocity).

The EI was described as an average rate measure to quantify the movements with high eccentric load. Unlike Study 1, where EI recorded was representative of purely activity, a training session contains intermittent rest periods within the session, and the periods of inactivity might confound the results if a volume measure was utilised. Hence, EI was presented in this study as EI rate, which was what EI is intended to be represented as. No significant relationship was found between BL and EI (Figure 21). Again this finding suggests that BL and EI possess a low shared (common) variance.

No significant changes in MVC force or muscle soreness of the quadriceps and hamstrings were evident before and 24 h after the training session 2 (Figures 19 & 20). This was also the case for other training sessions. It was found that the mean pre-training values of MVC force of the quadriceps was 871 N, which was greater than that reported by (Krustrup et al., 2011) from 7 first and second division Danish football players (596 N). This indicates that the players recruited in the present study were well trained, at least in terms of strength. It should be noted that the players experienced some degree of muscle soreness even before the commencement of the training (Figure 20). This may be due to the previous training session

or match they performed over the preceding weekend. The lack of changes in muscle damage markers may be due to the repeated bout effect, because the players trained regularly and performed similar activities repeatedly in their training sessions. It has been well documented in previous studies that muscles become less prone to eccentric exercise-induced muscle damage when the same or similar exercise is repeated (Newton et al., 2008; Nosaka et al., 2001; Stupka et al., 2001). The players monitored in this study were semi-professional players who trained twice per week with competitive games played at the weekends. The training game played during session 2 employed an opposing team with a lower playing standard. Due to the minimal changes in MVC and muscle soreness before and 24 h after training, no significant relationships were found between BL, EI or the muscle damage markers. It would be interesting in future research to investigate whether players who show higher EI in a more competitive and physically demanding situation also show greater decreases in muscle strength and increases in muscle soreness.

5.3 Conclusion

From the results of Study 1 and Study 2, it seems reasonable to conclude that BL is not a good indicator of eccentric loading, and EI is a better representation of eccentric loading. However, since EI is characterised as an average rate recorded over the entire session, the intermittent rest periods within a training session might affect the actual eccentric load of a training session. It was shown that EI was capable to differentiate between players with higher eccentric load compared to other players with lower eccentric load when the activity was relatively similar. However, the EI does not appear to be a perfect indicator of eccentric loading. Being an index that is presented as an average rate, the EI represents the average eccentric loading in a session but does not appear to account for the magnitude of the each eccentric load induced by the movements. There is a possibility that a low accumulation

of high magnitude eccentric load and a high accumulation of low magnitude eccentric load will affect the muscles differently. It was shown by Nosaka and Newton (2002) that a maximal eccentric contraction will induce a significantly higher magnitude of muscle damage and slower recovery rate compared with a submaximal eccentric contraction. Therefore, it would seem important for EI to account for the magnitude of each eccentric load to determine the likelihood of any injury risk or decrements in performance of the player.

5.4 Future Research Direction

In the present study, EI developed by Athletic Data Innovations was used with the assumption that it would quantify eccentric load better than BL. The results supported this assumption, however, actual eccentric loading was not clear from the present study, since the eccentric loading was assumed from the video analysis.

The utilisation of EMG combined with video motion analysis may be useful in assisting to quantify the magnitude of eccentric loading during CoD at different velocities by observing the eccentric phase of each CoD and quantifying eccentric muscle activity during the turn. GPS derived variables can also be compared to force data gathered from a force plate and muscle activity from EMG to determine the accuracy of the accelerometer measuring eccentric load. Furthermore, it also seems necessary to take into account the magnitude of each eccentric action performed as high magnitude eccentric loads will affect the muscle differently compared to accumulation of low magnitude eccentric loads.

It appears that it may be possible to fine tune EI in order to provide an even better indicator. Currently EI is presented as a measure of the average rate of eccentric load in a session, however, this does not appear to be fully representative of the actual activity period as training sessions contains intermittent rest periods. Future studies could attempt to isolate

the activity periods within a training session from the low activity periods to investigate the utilisation of EI to monitor eccentric loading in training.

The current study utilised a running drill consisting of a total of 11 actions found in an intermittent team sport with a total distance of 180 m. However, this does not represent the distances required in team sports. Future investigations may consider a running drill of a longer duration and incorporate more actions to better represent activities found in a game.

It was observed that exaggerated movement of the upper trunk could provide different accelerometer data, especially at higher velocities. Thus, positioning of the GPS unit should be considered to minimise such an effect.

The current study monitored only 6 players over 4 training sessions, and the sample size was too small. This was disappointing and due to the non-compliance of four of the subjects. Future research should consider a longer monitoring period with a larger sample size, in order to thoroughly investigate the capability of the EI as an eccentric load monitoring tool. Training sessions conducted over a varied range of activities that induce eccentric loading should be utilised to examine the sensitivity of EI to detect changes in eccentric loading between training sessions of different nature.

5.5 Practical Recommendations

From the findings of the current study, it seemed that EI was a better indicator of eccentric loading compared to BL. However, due to the various flaws presented within the thesis, it is unknown if EI is an accurate and practical indicator of eccentric loading. The studies presented possible applications of BL and EI, however, further investigations are required to clarify the uncertainties before EI or BL can be considered for practical application.

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APPENDIX

APPENDIX A: Information Letter to Participants (STUDY 1)

<u>Title of the project</u>

Monitoring Muscle Damage and Eccentric Load with GPS in Football Training

<u>Researchers and Contact details</u>

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You are invited to participate in this study. Participation in this study is voluntary and you are free to withdraw without prejudice at any time. If you wish to participate in this study, please sign the Informed Consent Form provided by the chief investigator after reading this information letter carefully.

Aim of Study:

This study aims to investigate the relationship between the eccentric index, body load and movements performed in football training sessions including practice matches.

Participant Requirements and Recruitment

You are asked to participate in this study based on the recommendation from your team coach. If you participate in this study, you will be asked to be involved in 2 testing sessions which comprise of: 1) 1 maximum effort sprint over 25m to determine peak velocity and 2) 2 trials of sprints over a pre-dertermined running drill which includes changes of direction and jumps at 30, 50, 80 and 100% of maximum velocity. You will be asked to wear a Gobal Positioning System (GPS) device during all sessions which will be housed within a purpose designed vest. Video recordings will be taken for all testing sessions for analysis purpose. The details of the testing procedures can be found below. All laboratory testing will be conducted on the football pitch located at Edith Cowan University (Joondalup). Each testing session will last approximately 1 hour.

Prior to the commencement of any testing, you will be required to complete a medical questionnaire. In the event that you identify a medical condition(s) that does not preclude you from participation in the study the researcher will take precautionary measures to minimize any incidents that may occur during laboratory testing.

This study has been approved by the ECU Human Research Ethics Committee.

TESTING PROCEDURES

Anthropometric Measures

You will undergo an anthropometric assessment (height and weight) before the commencement of the study; this will be done within the first session.

Maximum Velocity Test

Your maximal velocity over a distance of 25m will be determined with 3 bouts of a 25m sprint test. Peak Sprint Velocity will be determined with the use of a radar gun.

Exercise test session

GPS, HR and Video Data

During all testing sessions you will be required to wear a GPS device on your upper back within a purpose designed vest and a Heart Rate monitor that is attached to a strap that is worn around the chest.. Each session will be recorded using a video camera.

Pre-determined running drill

You will be required to perform 2 trials of a pre-determined running drill over a range of velocity calculated from the results obtained through the Maximum Velocity Test. You will be required to maintain the selected velocities (30% max, 60% max, maximum effort) as closely as you can while performing actions such as changing direction, jumps and coming to a complete stop as the instructions were called out during the test. You will be required to perform and maintain the required speed (30% max, 60% max) over 25m till 2 consecutive trials with speed no more than ± 0.1 m/s is achieved. The test will be repeated on a second session for test-retest reliability. Details of the running drill can be found at the end of this document in Figure 1.

Risks and Benefits

The associated risks with participating in this research are minimal; however the physical tests may induce some local muscular fatigue. In the unlikely event of an injury, the supervision team will have the adequate first aid training to assist with the acute injury management. By participating in this research you will be assisting to affirm a current practice of evaluating muscle damage used by coaches. Data from this study will determine whether body load and eccentric index measures collected from GPS units provide usable indicators of muscle damage and soreness. If data collected from the GPS is shown to be useful in determining the extent of muscle damage and soreness, it could then be utilized as a more convenient approach to determine muscle damage than the current employed muscle damage and soreness measurements.

Confidentiality of information

All data obtained as part of this research will be retained for five years and stored in a locked filing cabinet in the office of the chief investigator at Edith Cowan University. All records containing personally identifiable data will remain strictly confidential and no information leading to the identification of participants will be released. The research team named below will access to your testing results, as well as potential research assistants who may be used for data entry purposes. Data obtained for this research will potentially be published in scientific journals and (or) presented at conferences. If this is the case, your data will be de-identified, with no personal information identifying you being published or presented. You will be provided with a copy of the results if you require.

Voluntary participation

Your participation in this study is entirely voluntary. No explanation or justification is needed if you choose not to participate.

Withdrawing consent to participate

You are free to withdraw your consent for further involvement in the research project at any time. If you choose to withdraw, you understand that any personal information collected up to that point in the study may be utilised for the project.

Questions and/or further information

For inquiries or additional information, please do not hesitate to contact us.

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Independent contact person

If you have any concerns or complaints about the research project and wish to talk to an independent person, you may contact:

Research Ethics Officer

Human Research Ethics Committee

Edith Cowan University

270 Joondalup Drive

JOONDALUP WA 6027

Phone: (08) 6304 2170

Email: research.ethics@ecu.edu.au

The Human Research Ethics Committee at Edith Cowan University requires that all participants are informed that, if they have any complaint regarding the manner, in which a research project is conducted, it may be given to the researcher or, alternatively to the Human Ethics Research Officer, Human Ethics Research Committee, Edith Cowan University, 270 Joondalup Drive, Joondalup, WA 6027 (Tel: 6304 2170, Email: research.ethics@ecu.edu.au). All study participants will be provided with a copy of the Information Sheet and Consent Form for their personal records.

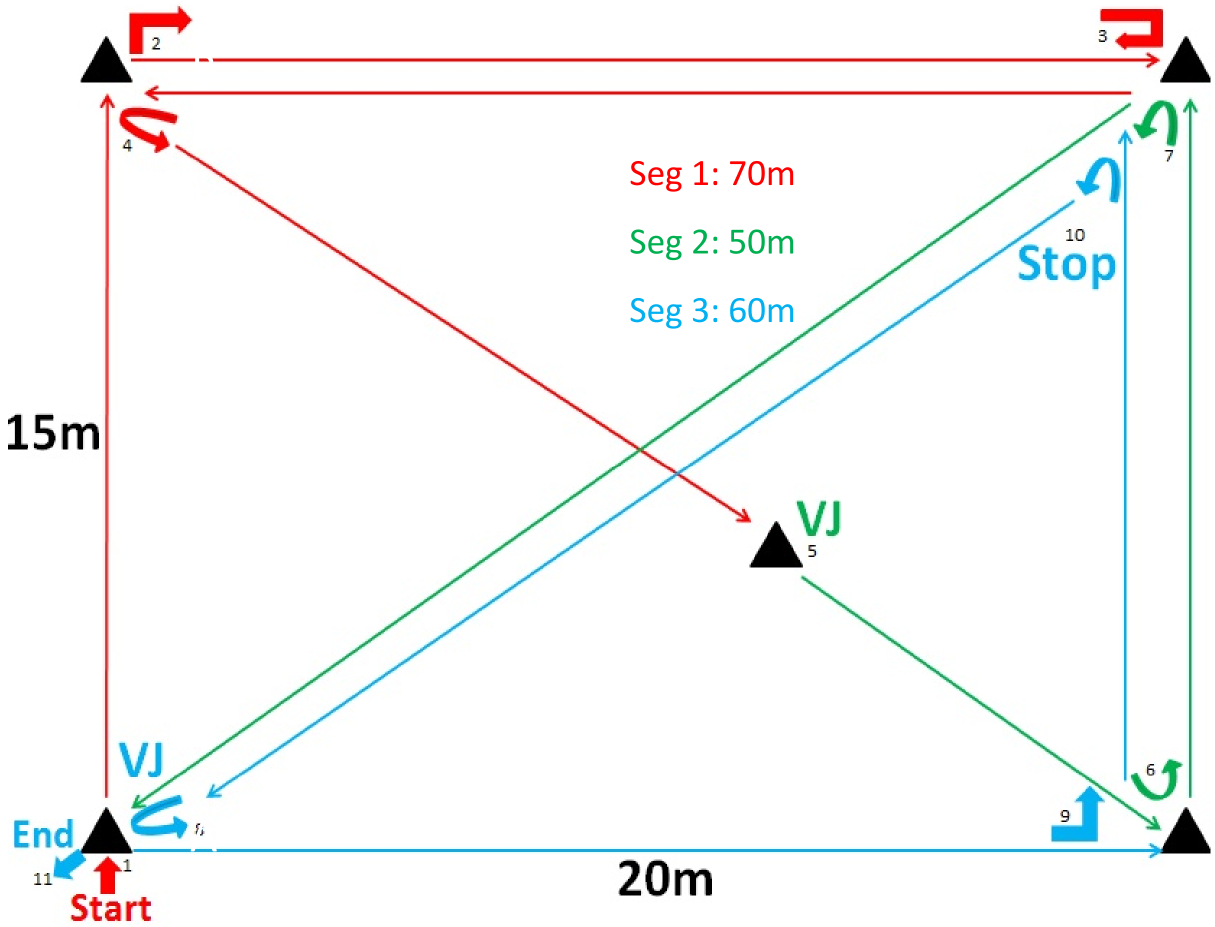

Figure 1: Pre-determined Running Drill

The subject will perform the drill as follow:

1. Run pass the start timing gates (T) and cone A towards cone B
2. Make a 90° turn to the right to cone C
3. Make a 180° turn back to cone B
4. Make a half turn to the left towards cone E
5. Perform a jumping header at cone E and run towards cone D
6. Make a half turn to the left towards cone C
7. Make a half turn to the left towards cone A
8. Perform a jumping header at cone A and make a half turn to the left towards cone D
9. Make a 90 ° turn to the left towards cone C
10. Come to a complete stop and make a half turn towards cone A
11. Run past cone A and the end timing gates to conclude the drill

Figure 2: Instructions for Pre-determined Running Drill

APPENDIX B: Information Letter to Participants (STUDY 2)

<u>Title of the project</u>

Monitoring Muscle Damage and Eccentric Load with GPS in Football Training

<u>Researchers and Contact details</u>

Vincent Yeo, CSCS

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Mob: 0412086532

Email: c.yeo@ecu.edu.au

You are invited to participate in this study. Participation in this study is voluntary and you are free to withdraw without prejudice at any time. If you wish to participate in this study, please sign the Informed Consent Form provided by the chief investigator after reading this information letter carefully.

Aim of Study:

This study aims to investigate the relationship between the eccentric index, body load and changes in indirect markers of muscle damage (MVC, CMJ, ROM, CK, and muscle soreness) in football training sessions including practice matches.

Participant Requirements and Recruitment

You are asked to participate in this study based on the recommendation from your team coach. If you participate in this study, you will be asked to be involved in 10 testing sessions which comprise of: 1) two familiarisation sessions, including one session in which you

complete a 30-15 Intermittent Fitness Test and a Repeated Sprint Test, 2) 8 testing sessions which will involve collection of a finger prick sample of blood to assess plasma creatine kinase (CK), and countermovement jump (CMJ), range of motion (ROM), muscle soreness (DOMS) and maximum voluntary contraction (MVC) strength measurements, before, 1 hour and 24 hours after each training session. You will be asked to wear a Gobal Positioning System (GPS) device during all training sessions which will be housed within a purpose designed vest. The details of the testing procedures can be found below. All laboratory testing will be conducted at the Biomechanics Laboratory (Building 22) at Edith Cowan University (Joondalup) while all training sessions will be conducted on the football pitch located at Edith Cowan University (Joondalup). Each testing session will last approximately 1 hour to 90 minutes.

Prior to the commencement of any testing, you will be required to complete a medical questionnaire. In the event that you identify a medical condition(s) that does not preclude you from participation in the study the researcher will take precautionary measures to minimize any incidents that may occur during laboratory testing.

This study has been approved by the ECU Human Research Ethics Committee.

TESTING PROCEDURES

Familiarisation session

During the first laboratory visit, you will undergo an anthropometric assessment (height and weight) and familiarisation with the protocols required for the study (MVC, CMJ, ROM, CK, and muscle soreness). This session will last for approximately one hour. A second familiarisation session will be set one week later and it will consist of the same protocols as those of the first familiarisation session and a 30-15 Intermittent Fitness Test and a Repeated Sprint Test.

30-15 Intermittent Fitness Test

You will attempt to complete a series of shuttle running lasting for 30 seconds for each running stage, with 15 second passive recovery periods between each running stage (Buchheit, 2008) (Buchheit, 2008)(Buchheit, 2008)(Buchheit, 2008)(Buchheit, 2008)(Buchheit, 2008)(Buchheit, 2008)(Buchheit, 2008)(Buchheit, 2008)(Buchheit,

2008)(Buchheit, 2008)(Buchheit, 2008)(Buchheit, 2008)(Buchheit, 2008)(Buchheit, 2008)(Buchheit, 2008)(Buchheit, 2008)(Buchheit, 2008)(Buchheit, 2008)(Buchheit, 2008)(Buchheit, 2008)(Buchheit, 2008)(Buchheit, 2008)(Buchheit, 2008)(Buchheit, 2008)(Buchheit, 2008)while wearing a heart rate monitor. The running course is set up in a straight line of 40 m marked with cones at the start, middle (20 m) and end points and safety cones positioned 3 metres from each end and 3 metres on each side of the 20 m cone. You will run at a pace determined by a pre-recorded audio beep. The running velocity is set at 8 km/h for the first 30 seconds of running with an increment of 0.5 km/h for every 30 seconds of running thereafter. The conclusion of the test will be determined when you are unable to maintain the required velocity for the "stage" by failing to reach a 3 m safety zone near each cone when the beep is signalled for 3 consecutive times or if you voluntarily conclude the test due to exhaustion. This test will be used to determine your maximum Heart rate (HR_{max}) .

Repeated Sprint Test

You will be required to perform 7 sprints (34.2m) with a low level active recovery period of 25 seconds between sprints to determine your repeated sprint ability with a component of changing direction. You will sprint forward as fast as possible from the 0 m mark to the 10 m mark, changing direction to the left and making a loop around a cone positioned 5m away. After returning to the main line of the course, you will sprint towards the end of the course pass a timing gate which will record your performance for the sprint. Passing the timing gate, you will have 25 seconds to job back to the starting point for a subsequent sprint. The test will conclude after all 7 sprints are performed. The course of the Repeated Sprint Test is included as Figure 1.

Exercise test session

You will be required to perform measurements to evaluate exercise-induced muscle damage before the commencement of each training session, 1 hour and 24 hours (the next day) after each training session. Details of muscle damage measurements are indicated below. In addition, a DEXA scan will be performed at the end of the study.

GPS, HR and Video Data

During all training sessions you will be required to wear a GPS device on your upper back within a purpose designed vest and a Heart Rate monitor that is attached to a strap that is worn around the chest.. Each training session will be recorded using a video camera.

Plasma CK Activity

Increases in muscle proteins such as Creatine Kinase (CK) in the blood are used to determine the amount of muscle damage one sustains after damage-inducing exercise. Capillary blood samples (~30 μ-L) will be obtained from the index finger with the use of a sterile lancet. This will only be performed during the pre-training and post 24 hours sessions.

Range of Motion

Swelling occurs in the muscle after exercises that induce muscle damage, therefore, it is expected that the range of which you can move your limb will decrease due to the effect of swelling. You will be required to lie on a massage table in a prone position with the knee slightly protruding from the end of the table. You will be asked to extend and flex the knee joint through the largest range of voluntary motion possible and the range of motion will be measured using a specialized instrument called a flexometer. The measurement will be repeated after a 30 s rest period.

Muscle Soreness

You will be asked to rate the level of soreness in your quadriceps, hamstrings and calf after a knee extension exercise, quadriceps stretch, hamstring stretch, calf stretch and 3 trials of drop jumps from a 60 cm box (1 trial each for evaluation of each muscle). This will be done by indicating the amount of discomfort you feel while performing the above task by marking on a 10cm line known as a Visual Analogue Scale (VAS).

Countermovement Jump

A countermovement jump is a jump performed by momentarily dipping down by bending your knees before jumping up into the air. You will be asked to attempt 2 trials of maximal vertical jumps on a force plate. All jumps will be attempted with hands placed on hips to prevent arm swing. A second jump will be repeated after a 10 s passive recovery.

MVC Strength

The Maximal Voluntary Contraction (MVC) Strength test is a test that determines the amount of force or torque one can generate over a certain amount of time. In this study, you will perform the leg extension (straightening the legs) variation of the test. You will perform the test before, immediately and 24 hours after each training session to determine any force loss due to muscle damage sustained during training. You will sit on a custom designed chair with the knee joint angle of the right leg adjusted to 70° (Peñailillo et al., 2013). The distance from the knee joint to the measuring device called a load cell will be measured during the familiarisation session and adjusted according to your measurements. You will then attempt 2 submaximal trials (~50% max effort) before being instructed to extend the knee as quickly as possible and generate maximal force for 3 s. This trial will be repeated after a passive recovery of 60 s.

DEXA Scan

Your body composition will be assessed by the research gold standard of dual energy x-ray absorptiometry (DEXA) which utilizes a small x-ray tube. The DEXA scan will be performed by an approved DEXA operator Certified in Radiation Safety. The DEXA scan will be performed at the end of the playing season.

Risks and Benefits

The associated risks with participating in this research are minimal; however the physical tests may induce some local muscular fatigue. In the unlikely event of an injury, the supervision team will have the adequate first aid training to assist with the acute injury

management. By participating in this research you will be assisting to affirm a current practice of evaluating muscle damage used by coaches. Data from this study will determine whether body load and eccentric index measures collected from GPS units provide usable indicators of muscle damage and soreness. If data collected from the GPS is shown to be useful in determining the extent of muscle damage and soreness, it could then be utilized as a more convenient approach to determine muscle damage than the current employed muscle damage and soreness measurements.

Confidentiality of information

All data obtained as part of this research will be retained for five years and stored in a locked filing cabinet in the office of the chief investigator at Edith Cowan University. All records containing personally identifiable data will remain strictly confidential and no information leading to the identification of participants will be released. The research team named below will access to your testing results, as well as potential research assistants who may be used for data entry purposes. Data obtained for this research will potentially be published in scientific journals and (or) presented at conferences. If this is the case, your data will be de-identified, with no personal information identifying you being published or presented. You will be provided with a copy of the results if you require.

Voluntary participation

Your participation in this study is entirely voluntary. No explanation or justification is needed if you choose not to participate.

Withdrawing consent to participate

You are free to withdraw your consent for further involvement in the research project at any time. If you choose to withdraw, you understand that any personal information collected up to that point in the study may be utilised for the project.

Questions and/or further information

For inquiries or additional information, please do not hesitate to contact us.

Investigator: Vincent Yeo, BSc, CSCS

Mobile: 0412086532

Email: c.yeo@ecu.edu.au

Supervisors: Prof Ken Nosaka, PhD

Tel: 6304 5655

Email: k.nosaka@ecu.edu.au

A/P Michael Newton, PhD, AEP

Tel: 9360 7346

Email: m.newton@murdoch.edu.au

Independent contact person

If you have any concerns or complaints about the research project and wish to talk to an independent person, you may contact:

Research Ethics Officer
Human Research Ethics Committee
Edith Cowan University
270 Joondalup Drive
JOONDALUP WA 6027
Phone: (08) 6304 2170
Email: research.ethics@ecu.edu.au

The Human Research Ethics Committee at Edith Cowan University requires that all participants are informed that, if they have any complaint regarding the manner, in which a research project is conducted, it may be given to the researcher or, alternatively to the Human Ethics Research Officer, Human Ethics Research Committee, Edith Cowan University, 270 Joondalup Drive, Joondalup, WA 6027 (Tel: 6304 2170, Email: research.ethics@ecu.edu.au). All study participants will be provided with a copy of the Information Sheet and Consent Form for their personal records.

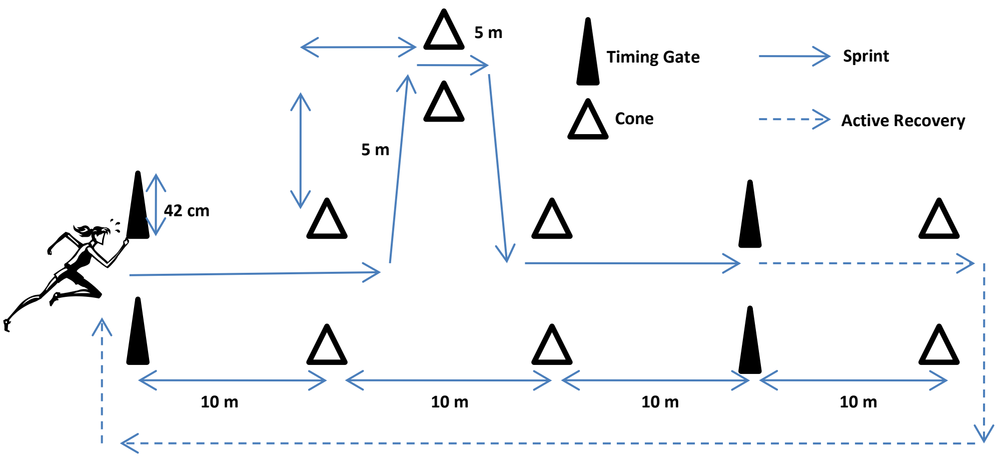

Figure 1: Repeated Sprint Test

APPENDIX C: Informed Consent Document (STUDY 1)

<u>Title of the project</u>

Monitoring Muscle Damage and Eccentric Load with GPS in Football Training

<u>Researchers and Contact details</u>

Vincent Yeo, CSCS

School of Exercise and Health Sciences

Edith Cowan University

270 Joondalup Drive, Joondalup, WA 6027

Mob: 0412086532

Email: c.yeo@ecu.edu.au

<u>Statement indicating consent to participate</u>

I, ______________________________, have read the information letter provided. Any questions I have asked have been answered to my satisfaction. I agree to participate in this activity, realising that I may withdraw at any time without reason and without prejudice.

I confirm the followings:

- I have been provided with a copy of the Information Letter, explaining the research study
- I have read and understood the information provided
- I have been given the opportunity to ask questions and I have had any questions answered to my satisfaction
- I am aware that if I have any additional questions I can contact the research team
- I understand that participation in the research project will involve:
  - A total of 2 testing sessions including 1 maximal velocity trial over 25 m.
  - Measurements which include GPS, video recording and the use of timing gates to determine the time to complete a pre-determined running drill.
  - Wearing a purpose designed vest which the GPS unit will be housed in
  - 2 trials of running and performing actions required in a pre-determined running drill at various speed which includes, changes of direction, jumps and complete stops.

- I understand that the information I provide will be kept confidential, and that my identity will not be disclosed without my consent
- I understand that the information provided will only be used for the purposes of this research project, and I understand how the information is to be used
- I understand that I am free to withdraw from further participation at any time, without explanation or penalty
- I understand that if I choose to withdraw part way through the study, the researchers may be unable to remove my data from the project
- I freely agree to participate in the project

Signed ………………………………… **Name**……………………………………….

Date……………

Signed by member of research team

…………………………………………………….

APPENDIX D: Informed Consent Document (STUDY 2)

Title of the project

Monitoring Muscle Damage and Eccentric Load with GPS in Football Training

Researchers and Contact details

Vincent Yeo, CSCS

School of Exercise and Health Sciences

Edith Cowan University

270 Joondalup Drive, Joondalup, WA 6027

Mob: 0412086532

Email: c.yeo@ecu.edu.au

Statement indicating consent to participate

I, ___________________________, have read the information letter provided. Any questions I have asked have been answered to my satisfaction. I agree to participate in this activity, realising that I may withdraw at any time without reason and without prejudice.

I confirm the followings:

- I have been provided with a copy of the Information Letter, explaining the research study
- I have read and understood the information provided
- I have been given the opportunity to ask questions and I have had any questions answered to my satisfaction
- I am aware that if I have any additional questions I can contact the research team
- I understand that participation in the research project will involve:
    - A total of 10 testing sessions including 2 familiarisation sessions and the measurements before, 1 hour and 24 hours after 8 training sessions.
    - The measurements include heart rate, range of motion of the knee, muscle soreness, countermovement jump, plasma CK activity and maximum voluntary contraction strength during knee extension
    - A small sample of blood drawn from my finger before and 24 hours after each training session for analysis of plasma CK
    - Performance of maximal isometric knee extensions; which involves an outward kicking like action while sitting on a purposed designed chair.
    - A DEXA scan that will expose me to a very small dosage of radiation taken after the season (less than that received on a aeroplane flight from one side of Australia to the other)

– Video recordings will be taken during each training session (6 sessions)

- I understand that the information I provide will be kept confidential, and that my identity will not be disclosed without my consent
- I understand that the information provided will only be used for the purposes of this research project, and I understand how the information is to be used
- I understand that I am free to withdraw from further participation at any time, without explanation or penalty
- I understand that if I choose to withdraw part way through the study, the researchers may be unable to remove my data from the project
- I freely agree to participate in the project

Signed …………………………………… **Name**……………………………………….

Date……………

Signed by member of research team

…………………………………………………….

APPENDIX E: MEDICAL QUESTIONNAIRE

Monitoring Muscle Damage and Eccentric Load with GPS in Football Training

SCHOOL OF EXERCISE AND HEALTH SCIENCES

MEDICAL QUESTIONNAIRE

Name: ______________________ Date of Birth: _____

Weight: ____kg Height: ___cm

Do you smoke? YES / NO

Have you ever been diagnosed with:

Being overweight? YES / NO

High blood pressure? YES / NO

Diabetes? YES / NO

Asthma? YES / NO

Any bleeding disorders? YES / NO

Do you have any reason to believe that you are more at risk of cardiovascular disease than a normal member of the population of the same age and sex?

YES / NO

If YES please provide details

Is there anything that you are aware of that may limit your capacity to exercise? (e.g., Chronic back pain and/or other joint pain, severe headaches?)

YES / NO

If YES please provide details

Do you have any allergies?

YES / NO

If YES please provide details

Are you currently on any prescribed or non-prescribed medications?

YES / NO

If YES please provide details

Do you have any other complaint or any other reason that you know of which you think may prevent you from participating in and completing this experiment?

YES / NO

If YES please provide details

I believe that the information that I have supplied is true and correct.

Signature :

Date:

APPENDIX F: RESEARCH CHECKLIST

Monitoring Muscle Damage and Eccentric Load with GPS in Football Training

— Final Checklist for Participant —

1. Are you aware that if you feel uncomfortable with any testing procedure you should tell the researcher immediately, and that YOU CAN STOP your participation at any time?
   YES / NO

2. Are you aware that this study comprises of 10 sessions including 2 familiarisation sessions (an incremental running test to maximal aerobic speed will be performed in one of the sessions), and laboratory-based testing sessions performed before, immediately and 24 hours after 8 training sessions over 6 weeks?
   YES / NO

3. Are you aware that you will be required to spend additional time outside of standard training (1 hour before, 1 hour after and 1 hour on the subsequent day after training) for lab testing sessions?
   YES / NO

4. Are you aware that, although very rare, maximal exercise (30-15 Intermittent Fitness Test) can result in fainting, severe exhaustion or cardiac events leading to death?
   YES / NO

5. Are you aware that the fatigue caused by maximal exercise (30-15 Intermittent Fitness Test) can impair your ability to perform tasks such as driving for a short while after the cessation of exercise?
   YES / NO

6. Are you aware that you may experience some discomfort (stretching sore muscles) during the test trial sessions?
   YES / NO

7. Are you aware that a small blood sample will be taken during each test session via a finger prick?
   YES / NO

8. Are you aware that there might be a minor risk of injuring your lower limb joints (knees and ankles) while performing a drop jump?
   YES / NO

9. Are you aware that you are required to wear a vest with GPS device on your upper back and a Heart Rate Monitor across your chest during the 8 training sessions that the study will be observing?
   YES / NO

10. Are you aware that you will be exposed to a small dose of radiation while undergoing a DEXA scan to determine your body composition?
   YES / NO

11. Are you aware that video recordings will be taken throughout the entire proceedings of the study?
   YES / NO

12. Are you aware that data and images recorded may be used in publications and presentations?
   YES / NO

Name of volunteer: ____________________________

Signature of volunteer: _________________________

Date: _______________

APPENDIX G: RESEARCH TESTING SHEETS

Monitoring Muscle Damage and Eccentric Load with GPS in Football Training

Data Collection Sheet (Pre) Session: _____

Name: __________________________ Age: ______________

Height: ___________________ Weight: ____________ HR_{max}: ____________

CK: _____________________

Range of Motion:

Fully Extended: __________ **Fully Flexed: _____________**

Muscle Soreness:

Stretch

Pre Angle: _______________

VAS (Quads)	
VAS (Hams)	
VAS (Calf)	

Knee Extension

VAS (Quads)	

Drop Jump

VAS (Quads)	
VAS (Hams)	
VAS (Calf)	

Countermovement Jump:

Trial 1		**Trial 2**	
Peak Force		**Peak Force**	
Peak Power		**Peak Power**	
Jump Height		**Jump Height**	

MVC

Load Cell Position: ________

Trial 1	
Trial 2	

Monitoring Muscle Damage and Eccentric Load with GPS in Football Training

Data Collection Sheet (Post 24 Hour)Session: _____

Name: ___________________________ Age: _______________

Height: ____________________ Weight: ____________ HR_{max}: _____________

RPE: ____________________

CK: _____________________

Range of Motion:

Fully Extended: __________ **Fully Flexed: ____________**

Muscle Soreness:

Stretch

Pre Angle: _______________

VAS (Quads)	
VAS (Hams)	

VAS (Calf)	

Knee Extension

VAS (Quads)	

Drop Jump

VAS (Quads)	
VAS (Hams)	
VAS (Calf)	

Countermovement Jump:

Trial 1		**Trial 2**	
Peak Force		**Peak Force**	
Peak Power		**Peak Power**	
Jump Height		**Jump Height**	

MVC

Load Cell Position: ________

Trial 1	
Trial 2	

Name:__________ GPS:_ Session:_______

Height :_________

Weight:_________

Max Velocity T1: __________

Max Velocity T2: __________

Max Velocity T3: __________

Radar Gun

Peak Velocity T1: __________

Peak Velocity T2: __________

Peak Velocity T3: __________

Max Speed:__________

T1 30%:_____S:__

T2 30%:_____ S:__

T1 60%:_____ S:__

T2 60%:_____ S:__

T1 Max:_____ S:__

T2 Max:_____ S:__

Monitoring Eccentric

Load with GPS in

Football Training

30% Speed:______

60% Speed:______

Data Collection Sheet (Pre) Session:__________ Name:___________

Player Number: ___________

CK: _________

RPE: ____________

Visual Analogue Scale

Quad Stretch

Hamstrings Stretch

Calf Stretch

Countermovement Jump

Leg Extension

Monitoring Eccentric Load with GPS in Football Training

Data Collection Sheet (Post 24h) Session:__________ Name:__________

Player Number: ___________

CK: _________

RPE: ____________

Visual Analogue Scale

Quad Stretch

Hamstrings Stretch

Calf Stretch

Countermovement Jump

Leg Extension

Monitoring Eccentric Load with GPS in Football Training