LONG-TERM ASSOCIATIONS BETWEEN SUBJECTIVE RATINGS OF WELLNESS AND EXERTION AND PARAMETERS OF TRAINING LOAD IN ELITE SOCCER OVER TWO SEASONS.

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Abstract

The purpose of this study was to investigate longitudinal relationships between subjective (self-reported) measures of readiness prior to training and exertion post-training with objective parameters of training performance measured via body-worn global positioning systems (GPS). Data was collected over a two-season period with 36 elite Premiership soccer players (16 players from the 2013/14 season; 20 players from the 2014/15). Subjective ratings of muscle soreness (MS) and fatigue (Fat) were collected prior to training sessions two days before a match. Sessional load (rating of perceived exertion x session duration) (sRPE) was measured following each session. GPS metrics of total distance covered (TD), high-speed running (HSR) and dynamic stress load (DSL), were significantly associated with subjective measures post-training. However, correlations between pre-training MS and HSR were discovered for the squad during the 2014/15 season. These observations were positive which showed increased muscle soreness correlated with increased HSR, which was not expected as increased muscle soreness would result in lower higher speed activity. Individual analyses revealed that 25% of the players demonstrated negative moderate or strong associations presenting that decreased muscle soreness is correlated with a decrease of HSR and TD. Post-training subjective ratings both presented strong associations at squad level between increased sRPE and increased DSL, HSR and TD. At the individual level 50% of players presented moderate to strong associations between sRPE and TD, and between HSR and DSL over both seasons. When examined over a combined two season period again squad pre-training subjective measures did not give any clear indication on performance levels within the following training session. There where individual instances of significant associations between pre-training subjective measures and GPS metrics. In addition, good associations between sRPE and both TD and DSL across both seasons provide new evidence for the use of post-session RPE as a robust indication of training performance within elite level soccer.

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Glossary of Terms

Name	Abbreviation	Definition
Total Distance (m)	TD	Total distance covered in metres.
High Speed Running	HSR	Total Distance covered at speeds greater than 5.5 m/s and lower than 7 m/s. This is presented in metres.
Dynamic Stress Load	DSL	A measure of total weighted impacts established from foot contact with the ground. Calculated automatically with a custom algorithm derived from the (x) and (y) axis within the accelerometer Statsports software. The measure of the weight of impacts are grouped individually through convex shaped function. The method suggests that an impact of 4g is twice as hard as an impact of 2g. The impacts are totaled, finally scaled to give workable values expressed in arbitrary units (AU).
Rating of Perceived exertion	RPE	A method of quantifying the subjective perception of physical exertion level, i.e. how hard you feel your body is working. It is based on the physical sensation a person experiences during physical activity, including increased heart rate, increased respiration or breathing rate, increased sweating and muscle fatigue. It is measured by a numeric value rating scale (from 6-20; with 20 representing maximal exertion) derived from Gunnar Borg.
CR10 Scale		A modification of the original Borg 6 – 20 scale. A category (C) ratio (R) scale which is scored 0-10 on

		the difficulty of the activity. The scale ranges from 0 (at rest) to 10 (very strenuous activity).
Sessional load	sRPE	The combination of an athletes CR10 RPE score multiplied by the session duration. It is an arbitrary value presented as a single number reflecting the severity of internal training load.
Internal Training Load		The relative physiological and psychological stressors imposed on an athlete during training or competition. This is measured using heart rate, blood lactate, oxygen consumption, and rating of perceived exertion (RPE).
External Training Load		Objective measures of the work performed by an athlete during training or competition, assessed independently of internal workloads. Common measures of external training load include power output, speed, acceleration, time-motion analysis and global positioning system (GPS) parameters.
Muscle Soreness	MS	The sensation of discomfort or pain felt in the skeletal muscles following physical activity. Measured on a rating scale of 1 – 10 (1 = minimal pain or discomfort / 10 = a lot of pain or discomfort).
Fatigue	FAT	A feeling of exhaustion and decreased capacity to compete physically and mentally. When the body is demonstrating a reduced ability to work efficiently. Measured on a rating scale of 1 – 10 (1 = minimal fatigue / 10 = a lot of fatigue).
Training Impulse	TRIMP	Banister (1991) developed a heart rate method to quantify training load. Banisters TRIMP takes into consideration the intensity of exercise as calculated by the heart rate (HR) reserve method and the

		duration of exercise. The mean HR for the training session is weighted according to the relationship between HR and blood lactate as observed during incremental exercise and then multiplied by the session duration.
Player Load		Instantaneous rate of change of acceleration divided by a scaling factor equation. A measure of the players work rate which gives one number. It is a measure of load independent on distance, which monitors movement and impact performance. Measured instantly 100 times per second and then accumulated over time, which provides a total work rate over a session.
Total High Intensity running distance	THIR	Thorpe et al (2015) describes the use of Total High intensity running as distance travelled by a player greater than 14.4 kmh.
Training Load	TL	Training load can be quantified from markers of internal load i.e. (RPE, HR, TRIMP, Wellness questionaires) and external load i.e. (exercise prescription, time motion analysis, power output measuring devices). TL is mainly quantified by the use of RPE (Halson, 2014).

Chapter 1 – Introduction

Understanding and influencing player performance is vital to coaches and sport scientists operating within elite soccer. Excessive training loads may lead to accumulated fatigue which increases the risk of injury when asked to train at the same level in a fatigued state (Barnett, 2006). Similarly, a training load that does not progressively increase with player fitness might also be detrimental to training adaptations and, ultimately, performance (Borresen & Lambert, 2009). Therefore, administering the correct load to induce the required training responses could allow for maximal adaptations and improvements in performance and fitness (Brink et al. 2015, Castanga et al. 2009, Manzi et al. 2013), while also protecting players from injury (Gabbett et al. 2013).

Consequently, it is important to monitor players' well-being and their associated training performance. Well-being of a player can be predicted by recording their subjective feedback regarding mental and physical condition (Nédélec et al. 2012). Individual ratings of muscle soreness, fatigue (neuromuscular), sleep duration and sleep quality and general stress (sport or non-sport related) can be used as subjective markers of readiness to train. Subjective ratings of sRPE can be implemented with various scales; CR-10, CR-100 or 6-20 scales (Foster et al. 2011). Questionnaires are the most common means of collecting pre-training subjective ratings from players (Taylor et al. 2012). Applications on electronic tablet platforms allow for quick monitoring of subjective wellness. The process makes it less time consuming, more efficient and more engaging for athletes (Saw et al. 2016). Subjective information on tiredness and exertion can also be collected post-training to assess physical performance within training (Govus, et al. 2017). Ratings of perceived exertion provide an indication of the internal training load. (Foster et al. 2011, Los Arcos et al. 2014, Alexiou & Coutts 2008, Impellizzeri et al. 2004). Despite developments in obtaining more subjective feedback of RPE and perceived wellness scores from elite players, there is a lack of explored associations between subjective markers of readiness to train and/or training exertion. This could affect their physical performance during a long-term training programme.

Although it is recommended to obtain trunk-mounted GPS data during every field training session (Gabbett et al. 2013, Rogalski et al. 2013), few investigations have associated those training measures with subjective ratings of well-being and exertion. Recent studies have examined associations between subjective ratings (pre- and post-training) and physical performance during training (Thorpe et al. 2015, Guadino et al. 2015, Scott et al. 2013). Significant positive associations between high speed running (HSR) and fatigue were observed over a two-week in-season period within an elite English Premier League club. However, no significant associations between HSR and muscle soreness, heart rate recovery and sleep quality were found (Thorpe et al. 2015). The use of RPE sessional load, which includes a rating of perceived exertion multiplied by duration (sRPE) is a more commonly used measure of internal load (Manzi et al. 2013). Other studies have found that external training load markers of HSR, impacts and accelerations of English Premier League players were influencing measures of RPE and sRPE (Taylor et al. 2012). It was found that HSR, number of impacts and accelerations were moderately predictive of sRPE. Further investigations within Australian rules A-League football between external load and internal markers of fatigue discovered significant correlations between total distance (TD), low speed activity and internal markers of fatigue and sRPE (Scott et al. 2013). In addition, HSR and very high-speed running presented significant correlations with sRPE (Scott et al. 2013). In summary, subjective exertion ratings have good relationships with external markers of training in different team sports. The reviewed studies conducted research over different durations which were mainly 4 weeks or less, investigating either post-training subjective ratings or pre-training subjective ratings and their relationships with external training markers derived from trunk-mounted GPS.

Chapter 2 – Literature Review

Football is one of the most popular sports in the world, with over 265 million people participating (FIFA, 2007). The actual game has not significantly changed over the decades. Sir Alex Ferguson provided a statement “sport science without question, is the biggest and most important change in my lifetime. It has moved the game onto another level that maybe we never dreamt of all those years ago. Sport Science has brought a whole new dimension to the game” (Bucheit, 2017). An increase of knowledge, understanding and technology within sport science has helped practitioners all around the world, with the internet creating a platform for innovative ideas and resources within the industry.

A literature review was undertaken of all the main topics surrounding performance monitoring research. Investigations of subjective ratings pre- and post-training were examined, highlighting areas for improvement. Particularly, the review highlighted how subjective ratings were related to GPS-derived measures of performance during elite level training.

2.1 Demands of football

Football is an intermittent team sport game played over 90 minutes, by two teams comprising of 11 players each. High intensity running distance (a combined distance of high-speed running and sprinting ($\geq$19.8 km . h^{-1}) has increased by 500m per match on average, with sprint distance (m) increasing by average 100m per match over a seven-season period (2006/07-2012/13) within Elite English Premier League match play (Bush et al. 2016). Published literature suggests training performance has been monitored in elite sport using micro-technology. This includes a global positioning system (GPS) and an accelerometer in a unit that is worn by each player, and provides information on player position, speed and acceleration throughout a training session (Carling et al, 2008, Gabbett. 2013, Ingebrigtsen et al. 2015, Guadino et al. 2015). The units are typically fixed within a small, elasticated pocket on the back of a vest worn by each player. A player’s movement data can be used to estimate training performance or training load using parameters such as distance covered, the amount of high speed and low speed running and the number of rapid changes in direction including accelerations and decelerations. In addition, dynamic stress load a measure of accumulation of accelerations, decelerations and impacts measuring biomechanical stress and load upon the body (Vanrenterghem, et al. 2017) Monitored as the total of weighted impacts and a measure of the foot contacts with the ground. The value is calculated automatically with a custom algorithm derived from the (x) and (y) axis within the accelerometer Statsports software. It is a measurement of the weight of impacts which are grouped individually through a convex shaped function. It is a specific magnitude of acceleration above 2g from a ground contact of an individual and may identify periods of increased loading.

2.2 Monitoring Performance

2.2.1 Field body worn device monitors

Due to the increase in physical and tactical performance within soccer, physical monitoring of the player has become a key part of daily practice. With the requirement for scientific rationale to support the planning and structure of training, numerous quantification systems have been developed over the years to monitor training load (Malone et al, 2017). Linking relationships between physical performance markers could provide even better-quality data towards helping the athletes. This could be examined by monitoring players/athlete's wellness to determine links with physical performance markers. Physical performance markers can be monitored either by subjective markers such as RPE or objectively by GPS. Internal training load (ITL) has been historically known within the literature as the main quantifier of training loads (Borg 1982, Foster 2001;2010). The most common way of analysing internal training load is by using subjective ratings of perceived exertion and heart rate measures during exercise (Foster, 2001). ITL is the physiological response from an external TL set within training. The measure of external loading for players can be derived from the players' movement during training. Devices such as miniature global positioning systems (GPS) mounted on the trunk (which have a built-in accelerometer), have become a popular method of estimating external load within team sports (Aughey, 2011). There is currently a lack of quantified data suggesting external load has led to responses within subjective measure of pre-training wellness of players (Malone, 2015). Scott, et al. (2013) assessed internal load methods of sessional RPE and HR based methods against measurements of player movements to assess the use of GPS and accelerometer technologies in estimating external training load. The study suggested that lower speed activities and total volume of the session are related to internal measures of HR and sRPE.

However, there were limited identified relationships between HSR and HR measures. This could be explained by short intense blocks of high speed activity having less an effect on heart rate responses. Casamichana et al, (2013) also examined similar markers of internal and external load, specifically investigating an equation of player load. This consisted of markers of the number of accelerations and found large relationships between internal markers of load with external markers. Relationships were found between internal markers of load and higher speed activities. These were trivial compared to the lower speed more volume-based parameters. Internal load plays a vital role within training, however improvements in player monitoring has allowed improved external markers. The literature suggests that lower volume-based measures are strongly related to all internal measures of heart rate and sRPE.

2.2.2 Physiological mechanisms of Well-being factors

Physiological mechanisms during exercise is important for athletes and practitioners to understand adaptation of athletes and monitor performance capabilities. Physiological monitoring is most commonly examining fatigue in addition muscle soreness of athletes (Thorpe. et al, 2017, Halson, 2014). Fatigue has been a complex mechanism for definition and the numerous varieties of possible mechanisms. Throughout the literature the common trend of definition has been that fatigue is the failure to maintain the required or expected force output (Halson 2014, Enoka. et al 2008). The nature of fatigue will depend on the characteristics of exercise, as during a marathon run fatigue will be different from a series of repeated sprints (Finister & Drory, 2016). Fatigue will not be caused by one single factor, and various mechanisms are involved which all have a contribution to the task being performed (Enoka. et al 2008, Sakkas. et al 2008) It has been shown in the literature that development of fatigue at the cellular level, which can be grouped into two mechanisms that are responsible for the inhibition of muscle function during fatigue are; impairment at the level of activation and, impairment of the actin-myosin interaction (Cooke, 2007) . Which within team sport fatigue is an important monitoring tool to understand as it will offer insights into if players are adapting to the stresses put on them during training and competition (Thorpe. et al 2017).

Additional physiological mechanism of well-being factors is Muscle soreness, which can be known as Delayed onset muscle soreness (DOMS). This is classified as a type I muscle strain injury which presents with tenderness or stiffness or palpation (Gulick et al, 1986), This is usually associated with high force muscular work and is precipitated but eccentric actions (Close. et al, 2005). It has been shown that the main contributing factor of muscle soreness is a combination of and inflammatory response of connective tissue or muscle damage (Chung. et al, 2003). Muscle soreness and the causes of this may result in alterations in muscle function and joint mechanics during exercise (Rowlands. et al, 2001). Which for an elite athlete with additional mechanisms of soreness may cause significant alterations and a reduction in performance and optimal training intensity.

2.2.3 Pre-training well-being

The management of training performance and overtraining can be difficult. Players can go through periods of extremely high training volumes with limited recovery periods during a season (Halson. et al, 2002). Monitoring recovery and fatigue alongside physical performance markers is key to preventing overtraining syndrome (Foster, 1997, Saw, 2015, & Gallo et al, 2015). The management and periodization of training loads will help prevent overtraining from occurring. Published literature suggests there are a variety of practical measurement tools to monitor fatigue and training status of athletes (Saw, 2015). It is still unclear which physiological and subjective measures are the most beneficial for athlete monitoring. It is known that being able to measure performance markers (e.g. counter movement jump/ yo-yo test) of players is the ultimate indicator of performance, however it is not practical to implement these tests daily (Currell & Jeukendrup, 2008). Practitioners, therefore need to examine different ways to monitor over-training. Self-reported questionnaires are the most common choice by practitioners to monitor fatigue and over-training (Taylor et al, 2012).

The most common sport-specific subjective rating measures to assess well-being are the Profile of Mood States (POMS); the Recovery Stress Questionnaire for Athletes (RESTQ-S) (Kallus, 1995); the Daily Analyses of Life Demands of Athletes (DALDA); Athlete Burnout Questionnaire (Radeke & Smith, 2001) and the Athlete Distress questionnaire (Main & Grove, 2009). These self-reported questionnaires are simple and non-invasive, making them easy to use in team sports. However, these established questionnaires are too lengthy and impractical for athletes to use daily (Twist & Highton, 2012). This has led to modified, shortened questionnaires being created to help practitioners monitor daily well-being (Buchheit et al, 2013; Coutts & Reaburn 2008; Gastin et al 2013; Hooper & Mackinnon 1995; Saw, Main & Gastin 2015). Modified questionnaires within the research have focused on keeping the number of questions down to five or less. The types of questions examined within the modified questionnaires focus on what the biggest impact on the athlete's performance will be. These questions are typically based on ratings of fatigue, muscle soreness, sleep quality and stress levels.

Research has investigated self-reported wellness questionnaires in responses to training and/or match load (Gallo et al. 2015). Historically, monitoring training or match load is completed using the internal and external measures. A large amount of research has examined the responses of self-reported well-being measures and training load in different sports such as rugby and Australian football (Gallo et al. 2015; Gastin et al. 2013; Halson et al, 2002; and soccer Thorpe et al. 2015; Moalla et al. 2016.)

The use of an internal marker of RPE is another subjective rating, which is commonly reported within the literature. RPE is a psychophysiological measure of internal load extensively used within different sports. It is used to monitor exercise intensity during physical activity. It also looks at the management between acute and chronic training load and maximal exercise (Roberston & Noble 1997); Eston 2012). The RPE scale was developed by Gunnar Borg in 1982. He wanted to answer the questions of how people were becoming more interested in how they feel during exercise. Gunnar wanted to prove the importance of relationships between objective measures of exercise e.g. heart rate measures, and subjective ratings of how people are feeling. Following this, Borg developed a scale of ratings of perceived exertion, where values ranged between 6 to 20. This was related to heart rate measures ranging from 60-200 beats per min. Borg made the point of having to use both internal markers alongside each other. This was because you can run at a single pace which achieves the same HR one day and report a 'fine' on the RPE scale. However, on another day running at the same pace you may report a higher score on the RPE scale due to physical or emotional stress. So, the scoring of RPE used alongside with HR measures as one score should be used as an accurate indicator of metabolic strain on an athlete (Borg, 1982).

Within the same study, Borg suggested the use of a new category ratio rating of perceived rating scale (CR10), thus to make a simpler scale to use that has positive attributes of a general-ratio scale. In later years this has been modified, making it easier and simpler for practitioners and athletes to use. Foster et al. (2001) used the same scale of 1-10, however modified the verbal language used. Results supported the use of the modified verbal CR10 RPE scale and sessional RPE. This was shown to have strong relationships with exercise scores such as TRIMP and summated HR zone scores. Additionally, when analysed through a regression slope, a consistent pattern of differences was reported between the HR summated zones and session RPE, both during steady state exercise and high intensity exercise. Due to this similarity and the ease of use of session RPE within team-based sport, it is a simple subjective score which provides a daily or weekly score of TL within team sports. This could be invaluable as the ability to monitor adaptation and the strain of training could potentially help in future outcomes of overtraining.

There is limited research investigating the relationship between modified daily wellness questionnaires, training and match loads of elite athletes. The topic was discussed between different sports, however these are mainly focusing between English Soccer and Australian rules football (Thorpe et al. 2015, Bucheit et al. 2013, Gastin et al. 2013, Gallo et al. 2016, Montgomery et al 2013; Moalla et al. 2016; Haddad et al. 2013).

During a periodised pre-season, it is important to monitor fitness and fatigue adaptations of athletes. During an Australian rules elite football camp in Qatar, Martin Buchheit (et al.2013) examined the usefulness of selected physiological and perceptual measures, to monitor fitness fatigue and running performance. Running performance and fitness were measured by a daily submaximal heart rate exertion and a Yo-Yo Intermittent recovery level 2 test (Bangsbo et al. 2008). Performance measures were monitored over the camp with standardised drills, which focused on total distance and higher speed distances. The drills included three separate exercises, all standardised and completed prior to training on four separate days. The drills were common drills in Australian Rules Football (ARF). However, the players still completed a normal training session around the standardized drills. This is would have a definite impact on the wellness scores as during a pre-season camp training loads will be high day to day (Coefficient of variation: CV 66%, $P<0.001$). The importance of measuring fitness and running performance was to see the players responses to running performance and fatigue markers. A modified psychometric questionnaire was used to assess general indicators of wellness (Hooper & Mackinnon. (1995). The questionnaire comprised of 5 questions relating to perceived fatigue, sleep quality, general muscles soreness, stress levels and mood. Each question was answered using a five-point scale. Within the two-week period, there were significant variations of day-to-day wellness and heart rate exertion (HRex). As predicted, after an intense two-week period of training physiological performance markers had improved. This was shown by improvements in the maximal Yo-Yo IR2 results. It was also shown that the sPRE (AU) value in an average week was more than double compared to a usual in-season training week. Interestingly, relationships between the different performance markers showed effect on each other. Monitoring fatigue during the season must also be considered. Negative effects were found between training load and wellness; meaning the higher the training loads the worse the wellness score the following day. This could be expected during a period of higher, more intense loads that lead to increased muscle soreness and fatigue. During the in-season period in Australian Football League the emphasis would be on maintaining rather than improving fitness produced in the training periods of the pre-season. Wellness scores (AU) are still affected daily were wellness scores can take, on average, 3 days to attenuate to show good recovery post game (Gastin, et al. 2013). This provides information on the importance of using a simple monitoring tool on acute training responses and recovery status the following day. In addition, this gives information on how any session can impact on wellness scores unless standardising a complete training session to specific drills. This is because it would limit the strength of data unless the additional load was considered. These two studies have given a clear insight into the importance of simple subjective monitoring tools and their effect on each other. During increased loads of a two-week pre-season training camp, correlations have been found between wellness scores and physical performance. An in-season study from Gastin, et al. (2013 found consistently low wellness scores over a 183 day in-season. This showed that increased loads during pre-season have more effect on muscle soreness compared to the typical maintenance loads of in-season.

Within the literature RPE has been proven to be a reliable measure of TL. However, GPS should be used as an objective measure alongside subjective RPE measure to improve accuracy. During the pre-season period of 2013, Gallo, et al. (2015) examined 15 skill-based training sessions from 36 male players from an AFL top league club. The skill-based sessions within this study were not given any description of the content within them. The trivial relationships between higher speed running activities, perceived wellness and RPE would suggest these skill-based sessions were lower in volume and intensity. The objective of the study was to examine the relationship between self-reported pre-training wellness score and external load parameters. A modified wellness questionnaire was used on a Likert scale of 1-7. Similar methods to Bucheit et al. (2013) were used which allowed for a more in-depth analysis with individual thresholds set from the GPS rather than using a general measure of RPE. Again, similar methods where used with wellness scores; an average from all five ratings of muscle soreness, sleep quality, fatigue stress and mood, *Z*-scores were used as a marker that was relative to the individual. Significant relationships were found between wellness *Z*-scores and GPS markers of performance from player load and player load. Player load considers the use of impacts, accelerations, decelerations, and has been defined as impacts on the body during performance (e.g. grappling). The skills sessions could have been at lower intensity due to trivial relationships with higher speed running activities. In contrast, strong relationships were found with player load metrics, which are shorter accelerations and decelerations. This would explain why the skill sessions were of lower volume and intensity. Like Gastin et al. (2013) used specific drills within their study, both studies did not consider the additional sessions which could affect perceived wellness, in a period where higher volume and intensity was usually prescribed. Final points from this study suggest that results from perceived wellness questionnaires can provide coaches with the ability to adjust TL were needed. Research has been conducted in different sports, which has included different data collection durations, types of training sessions recorded, and various metrics. Future research examining specific parts of a pitch session need to consider the additional pitch-based loading. In addition, skill-based sessions do not give a real representation of higher intensity sessions, such as small-sided games and match-play. Recent studies within soccer have expanded on these raised issues. A longer period of data collection across a season attempted to focus on intense training or match play. There was an improvement on methods used to minimize the variability of the data collected. However, readiness to train scores would be affected across a whole training session as it takes into account high intensity performance (Haddad, et al. 2013, Moalla, et al. 2016 & Thorpe, et al. 2015).

Following previous research there has been a need to examine longer durations of data collection and to conduct in-season analysis to establish if subjective wellness ratings influence performance. Two studies from Moalla, et al. (2016) and Haddad. et al, (2013) investigated a prolonged period of data collection and in-season training periods. In both studies, training load (TL) was calculated from the individual players RPE score. Pre-subjective wellness scores were also collected from the Hooper questionnaire (Hooper & Mackinnon, 1995). Haddad. et al, (2013) examined only RPE collected post a 10-minute sub-maximal running test performed prior to every training session, where data was collected during the last six weeks of a season to control variability in sessions. Moalla, et al. (2016) examined relationships between pre-subjective measures over a 16-week period. Split over three periods during pre-season, in-season standard, and in-season taper, 132 training sessions were examined. The study design included different time points in the season addressing some of the issues previously highlighted in the literature. Significant correlations were found between daily TL scores and the perceived sleep, fatigue, stress and muscle soreness. Correlations between TL, fatigue and muscle soreness were higher than the magnitude of correlations between stress and sleep. This suggests that TL affects more fatigue and muscles soreness parameters, than sleep and stress. However, accumulations of fatigue and muscles soreness affect sleep and stress. Haddad, et al. (2013) did not find any significant relationships between a post sub-maximal running test RPE scores and pre-subjective ratings. When comparing the two studies, when just standardizing performance to a certain part of a training session no relationships were found. Moalla, et al. (2016) found that when examining a full training session there was a significant effect on the pre-subjective measures. In addition, they suggest why and what part TL influences wellness and vice versa. These findings suggest that it was possible that relationships were found from an intense pre-season period. This explains the need to examine training load in more detail, given the limitations of RPE as a standalone measure. The use of GPS will provide more in-depth analysis of what the TL looks like, e.g. increased volume or intensity, and where in the session this was happening. Thorpe *et al*., (2015) used GPS within soccer over an in-season 17-day period to examine relationships between perceived wellness ratings and training load. Only one measure used from GPS total high intensity running distance (THIR = >14.4 kmh) was used as the indication of match and training load throughout the study. This was analysed against several fatigue markers, perceived rating of wellness, counter movement jump and heart rate variability. During the 17-day period when examining THIR as match and training load, there was a day-to-day variation of 115%. Similar to previous studies from Moalla, et al. (2016), you can expect high variation in session-to-session TL scores due to periodised planning and changes in session outcomes throughout the training week (Anderson, et al. 2015). Similarly, when the data collection is limited to a specific drill or part of training session, no significant findings were found (Gastin. et al, 2013 & Buchheit. et al,2013). These studies suggest how it is possible to present minimal variation, but still obtain data from a complete training session. Thorpe, et al. (2015) found no significant relationships between muscle soreness and sleep during an in-season period (compared to a pre-season period). The higher volumes and intensities during the pre-season training period has been associated with greater muscle soreness and reduced sleep. However, THIR was the only measure looked at that could affect perceived ratings of muscle soreness. THIR is used as a measure of intensity during a periodised plan used within football, however, within a standard training week higher intensity work can be low. Conversely, measures of volume within the research such as TD and RPE have shown substantial amounts of relationships. This suggests there is a rationale to examine if several GPS variables could have effect on muscles soreness and sleep.

2.3 Summary

Different cases have been put forward within the literature for time points and length during the season that data is collected over. It has been shown that during a pre-season period of data collection due to training volume and intensity results show significant relationships with perceived wellness ratings (Buccheit, et al. 2013, Gallo, et al. (2015) & Moalla, et al. (2016). There have been limited studies examining in-season periods of training and the relationship with perceived wellness, when during the competition period this could be the most crucial time to monitor fatigue and recovery (Thorpe, et al. 2015, Gastin, et al. 2013 & Haddad, et al. 2013). Studies examining only part of a training session, which either has been skill based or a sub-maximal running test found no relationships. However, when all parts of the field training were examined significant relationships where found. With the strong and moderate relationships there was high variability in the performance data and not much detail around why the relationships were found. This leaves gaps for future research to examine in more depth in-season practice, as relationships have been shown at a basic level of performance. It allows examination in more detail were these relationships are found specifically when using GPS to track performance. In addition, there is a need to minimise the variation when looking at all parts of a training session. Considering this evidence, the aim of this study was to investigate longitudinal relationships over an in-season period between subjective (self-reported) measures of both readiness to train and exertion post-training, with parameters of physical training performance (GPS). It can be measured over a prolonged period during one season. It was hypothesised that post-training perceived exertion would be consistently and strongly related to total distance covered and high-speed running during training. Moreover, from previous investigations it was predicted that measures of readiness to train would also be associated with HSR and dynamic stress load (DSL) parameters.

Chapter 3 – Methods

3.1 Experimental approach to the Problem

The first part of the investigation established the association between pre-training subjective ratings of well-being and movement characteristics during training using GPS body-worn, micro-technology. In the second part, it was sought to investigate the relationship between post-training subjective markers of well-being and training performance markers/metrics derived from GPS. The study only conducted analysis on complete field training sessions two days before match-play (MD-2). This was to minimise the variability between daily training sessions during a periodised program, were high variability has been shown in previous studies (Thorpe, et al. 2015, Moalla, et al. 2016). MD-2 was considered the most consistent session throughout both seasons compared to other training days (see appendix A.2) for comparison between training days during the week). MD-3 data shows the inconsistency of this day, supporting the selection of MD-2 (Appendix A.2). MD-2 sessions were described as high intensity training by the coaches and consisted of small-sided games and possession-based drills. This is verified objectively with the GPS data throughout the season as when examining previous research for day to day variability of training sessions and drills. It was important to minimise the variability (Thorpe, et al. 2015), the GPS data presented this as MD-2 was the most consistent highest intensity day as measured from the GPS variables, which was consistent throughout the seasons. In addition, with different weekly schedules there was also an inconsistency of certain training days. For example, with a midweek cup or league game, there would not be a MD+2 or MD-3 if playing Tuesday and then Sunday.

3.2 Pilot Study

Data was collected during a pilot period, which was a period during the 2013/14 English Premier League season, data was collected from 16 from a possible 22 outfield players (age 28.9±5.1 years; weight 80.2±8.6 kg; height 179±0.7 cm.) during normal training throughout a 25-week period (November 2013 – May 2014). Six players data was not collected was during this period. This was due to 1 x injury, 1 x left the club in January, 1 x joined the club in January, in addition 3 x players where left out of the study with lack of data to analyse.
As being the first season of data collection within elite level football using a long in-season period has helped with adherence issues that we found during this period. In addition, we changed the method for players answering the questionnaire from their own phone to handing around an iPad as shown below. It was discovered as well from the first season that education and understanding of wellness questionnaires, this was then addressed with moving in the main collection period. Results are not presented in the results section.

3.3 Subjects

During the 2014/15 English Premier League season, the same data was collected from 19 out of 24 outfield players (age 29.2±5.3 years; weight 81.4±7.9 kg; height 180.2±0.9 cm. 9 Defenders, 8 Midfielders and 3 Forwards) during normal training throughout a 35-week period (October 2014 – April 2015) (See appendix A.5 for player positional spread over the two seasons). Players data was not collected due to injury during the season and a transfer half-way through. Liverpool John Moores' Ethics Committee Board approved the current investigation.

3.4 Procedures

Over the two-season period, the data collection approach was consistent throughout. The study was conducted across two separate periods across two seasons. Within the second period compliancy of the players had improved during the 35 weeks. It was possible to improve upon the results found within the first season and then present any individual case studies of players across the whole period of 60 weeks.

On arrival for training, players answered the readiness and well-being questionnaire (Kitman Labs Injury Profiler, Kitman Labs Ltd. Dublin) on an Apple iPad (Apple computer Inc. California). Five questions in total were chosen similar to previous studies who have used a modified questionnaire (Buchheit, et al. 2013; Coutts & Reaburn, 2008; Gastin, et al. 2013; Hooper & Mackinnon, 1995; Saw, Main & Gastin, 2015). Three of the questions are a Likert rating of 1-10; muscle soreness (whole body) 1=no muscle soreness, 10=high level muscle soreness; fatigue (neuromuscular) 1=no fatigue, 10=extremely fatigued. The other two questions that were not used are sleep quality (which had a rating of good, average or poor), and general stress (with a rating of high stress, some stress and low stress). The literature presented that majority of wellness questionnaires Likert scales used were between 1-5 or a rating of 1-7 (Gallo, et al. 2015, Bucheit et al. 2013) The present study chose a Likert scale of 1-10, as this was the same as the current Likert scale players are used too with the RPE scale which as mentioned is a scale of 1-10. We felt this would be the easiest way to understand the ratings, rather than add a different scale in.

The present study only examined muscle soreness and fatigue, due to these being the most common variables indicating a change in performance levels. (Gastin, et al. 2013; Thorpe, et al. 2015) Post-training subjective markers of RPE were collected with a rating of 1-10; 1=rest; 10=maximal effort, which a marker of sRPE was derived from on Excel a calculation of a player's RPE 1-10 was then multiplied by the duration of the session to give sRPE . (Foster, et al. 2011) RPE was collected individually within 30 minutes of the completion of training rather than 5 minutes post session, ensuring true reflection on the whole session (Guadino, et al. 2015).

Indices of performance were monitored using a micro-technology device (STATSports viper, STATSports Viper, Northern Ireland). This device comprised a portable non-differential 10 Hz global positioning system, integrated with a 100 Hz 3D accelerometer, a 3-D gyroscope, and a 3-D digital compass. 10hz devices have been previously shown to provide, valid and reliable estimates of constant and sudden changes of velocity movements during linear, multidirectional team sport specific drills (Castellano, et al. 2011, Johnston et al 2014, Varley, et al. 2012 Coutts et al 2010). Each player had their own individual vest throughout the period. If the vest got damaged or stretched, it was replaced with a brand-new vest fitted to the player to minimize any movements of the vest. Each player was assigned their own unit for the duration of the study to minimize the inter-unit error. The location of the GPS unit on the player is located in the same position used within other team sport studies. The pod is placed in a fitted pocket at the rear of the vest located on the players trunk between the shoulder blades. (Harley, et al. 2010; Akenhead, et al. 2013; Whebe, et al. 2014; Nedergaard, et al. 2014) (See appendix A.8) Each unit was activated 20 minutes before training, to ensure a satellite signal acquisition of > 18 satellites. Post training the GPS units where collected and data was downloaded using the STATSports Viper version 1.2 software. The performance variables recorded during the training sessions included total distance (m), high speed running (>5.5m/s) (m), and dynamic-stress load which is a calculation total of the weighted impacts measured by foot contacts with the ground. It is calculated automatically with a custom algorithm derived axis within the accelerometer Statsports software. It is a measure of the weight of impacts which are grouped individually through a convex shaped function. Within soccer impacts are a mixture of collisions and step impacts, although dynamic stress load in soccer is dominated by running step impacts. As measured at a high sampling rate 100hz within the accelerometer, it allows to see what the extent is when the body has been “shaken up” (Vanrenterghem, et al. 2017) With the present study this is dynamic stress load within the Statsports software however across different sports and player monitoring software it can be known as most commonly PlayerLoad and BodyLoad all three concepts of the metric have been presented within the research as the measure of the biomechanical stress as the summation of impacts, accelerations and decelerations accumulated on the body during activity (Vanrenterghem, et al. 2017, Guadino, et al. 2015, Viper metrics, 2015, Lovell et al. 2013) The measure of external load on the body and understanding the biomechanical stress put on the body is important for practitioners especially in running based sports in addition to the physiological markers monitored such as (HR, RPE). It is commonly used within high level sports as a different measure to exposure the training loads put on players. Even though dynamic stress load has not been widely published within the literature it does have some evidence of the relation it can have to measuring training load. It allows practitioners over time to monitor the biomechanical load/stress.

3.5 Statistical Analyses

Analysis of all nine different correlations (Appendix A.1) were conducted on a squad group level first, as if it is possible to discover, on average, there was a general relationship between metrics that are important to examine on a group level. However, it is known that when looking at squad averages and general trends at group level, there could be many individual differences between the players. In addition, when analysing players physiologically, it needs to be examined on an individual basis. Each individual was examined for any relationships. Using statistical software Spss v21, pre-subjective measures of muscle soreness and fatigue, post subjective measure of perceived training load were associated within the Spearman's rho correlation as using ordinal and ranked data from the subjective rating Likert scales correlated to GPS metrics TD, HSR and DSL. The assumptions of the data are acceptable for the Spearman's rho correlation. Nine correlations in total (Appendix A.1). The process provided a p value to show statistically significant correlations ($p < 0.05$). If a correlation was found to be statistically significant it was then grouped by using the r-value from the calculation. The r-value provided a score to show weather a correlation was a moderate or a strong correlation, moderate r= .50 to .70, strong r= .80 to 1 (Hopkins, 2000). Within Hopkins research, both (2000) & (2009) he explains about setting thresholds to measure the magnitude of the correlation. There are different thresholds mentioned for small moderate and large ratios in Hopkins (2009) and Cohen (1998). Hopkins explains the use of custom thresholds based on magnitude and sample size. Other studies have used similar thresholds and magnitudes to the present study. Anything below a moderate correlation even if significant would not be considered further as with using 9 correlations in total there is a risk that significant correlations are found by chance alone.

Chapter 4 – Results

Throughout the 2014/15-season, analysis occurred firstly on a squad level (Tables 1 and 2) and then individual level. Data collected was divided into two categories, pre-training subjective measures against GPS metrics and, secondly, GPS metrics against post-training subjective measures. When analysing over the season relationships are expected to be found on a squad level, especially between performance markers of total distance (m) and high-speed running (m) and post training RPE scores. However, on a squad level no significant relationships of pre-subjective measures and GPS performance markers, results would be presented on an individual level of analysis as every player will give different results to how their body reacts to training. Not all individuals will show significant relationships between performance metrics and perceived wellness and post RPE, but it is expected that a number of individuals to present significant relationships.

4.1 Squad Results

4.1.1 Pre-Training Subjective Ratings

When examining pre-training subjective ratings of muscle soreness (MS) and fatigue (FAT) correlations with GPS metrics of TD, HSR and DSL, no significant moderate and strong associations over the investigation period were discovered during the season period at squad level. Table 1 displays relationships that were found, which were lower than moderate significance.

Table 1 - Squad associations between pre-subjective measure of muscle soreness and fatigue and GPS metrics TD, HSR, DSL 14.15 season.

Season	Subjective Rating	GPS Metric	R value	P value
14.15	MS	TD	.380	.024
14.15	MS	HSR	.426	.011
14.15	MS	DSL	.441	.008
14.15	FAT	TD	.446	.007
14.15	FAT	HSR	.397	.018
14.15	FAT	DSL	.486	.003

4.1.2 Post Training Subjective Ratings

During the collection period significant moderate and strong associations on a squad level were identified between perceived sessional load and DSL, HSR and TD. Similar findings during the 2014/15 season for associations of perceived post-training subjective measures for total distance *r*=.816 (p=<.005) and dynamic stress load *r*=.636(p=<0.05) were also observed (Table 2).

Table 2 - Squad associations between post-subjective measure of perceived sessional load and GPS metrics TD, HSR, DSL 14.15 season. (*. Statistically significant correlation)

Season	**Subjective Rating**	**GPS Metric**	**R value**	**P value**
14.15	sRPE	TD	.816*	.000
14.15	sRPE	HSR	.411	.000
14.15	sRPE	DSL	.636*	.000

4.2 Individual results

Examining results on a squad level tends to mask individual results. As grouped results will not present the individual differences as it will just present a group average, as within football yes, it is a team sport, however it is important we are delving deeper into the analysis of the individual player to understand how the each of the players body is feeling and not a general group feeling. Each player will be different and respond in a slightly different way to another player.

Table 3 – 14/15 Season Individual analysis of all nine correlations, presenting the spearman's Rho *R* value. *, shows significant relationship between the GPS metric and the subjective rating.

Player	Total Distance			High Speed Running			Dynamic Stress Load		
	MS	FAT	sRPE	MS	FAT	sRPE	MS	FAT	sRPE
1	-0.303	-0.308	0.853*	-0.177	-0.545*	0.725*	-0.141	-0.31	0.826*
2	-0.384	0.469	0.631*	-0.74*	-0.42	0.393	-0.317	0.469	0.431
3	-0.647*	-0.679*	0.699*	-0.423	-0.383	0.56*	-0.61*	-0.63*	0.661*
5	-0.038	0.28	0.761*	-0.313	0.091	0.21	-0.022	-0.016	0.779*
6	-0.67*	-0.217	0.588*	-0.379	-0.174	0.192	-0.67*	-0.282	0.615*
7	-0.617*	-0.703*	0.832*	-0.326	-0.609*	0.627*	-0.134	-0.469	0.849*
8	-0.099	-0.477	0.863*	-0.184	-0.477	0.426	-0.239	-0.43	0.831*
9	-0.473	-0.29	0.634*	0.005	0.232	0.548*	-0.478	-0.116	0.613*
10	-0.534*	-0.481	0.796*	-0.588*	-0.597*	0.521*	-0.565*	-0.411	0.805*
11	-0.207	-0.514*	0.801*	-0.259	-0.487	0.297	-0.061	-0.469	0.865*
12	0.338	-0.244	0.72*	0.1	-0.456	0.35	0.383	-0.308	0.759*
13	-0.416	-0.081	0.717*	-0.408	-0.108	0.369	-0.503*	-0.163	0.656*
14	-0.437	-0.266	0.696*	-0.344	-0.28	0.48	-0.421	-0.352	0.705*
15	0.257	0.169	0.63*	0.062	-0.057	0.201	0.25	0.047	0.298
16	0.052	-0.277	0.759*	0.01	-0.088	0.523*	-0.01	-0.22	0.609*
17			0.925*		-0.218	0.574*			0.864*

Table 3 gives a good representation of all the individual analysis across all nine correlations. In addition, it presents the most common significance between the pre and post subjective wellbeing. The majority of players showed strong significance on post training sRPE and all three metrics. However not every player showed a relationship between HSR and sRPE, this may be not the case for certain players for different reasons either they did not complete enough high-speed running during the session to have an effect from the position they were playing. HSR during an in-season period would be at a minimal maintenance dose so the effect that HSR would have on perceived exertion may be minimal for certain players, with the ability to cope with this amount.

It is clear to see that there are no trends within the pre-subjective wellbeing and their physical performance during training. There are only certain players within the group that have shown significant relationships between pre-training subjective ratings and GPS performance.

4.2.1 Pre-training Subjective Ratings

Figure 2 presents individual associations between pre-training subjective measures of muscle soreness and total distance for two players. Both players presented illustrate a statistical negative significant association (Player 1: r=-0.647, p=0.001; Player 2: r=-0.534, p=0.005). A decrease in MS ratings prior to training was associated with an increase of TD during training.

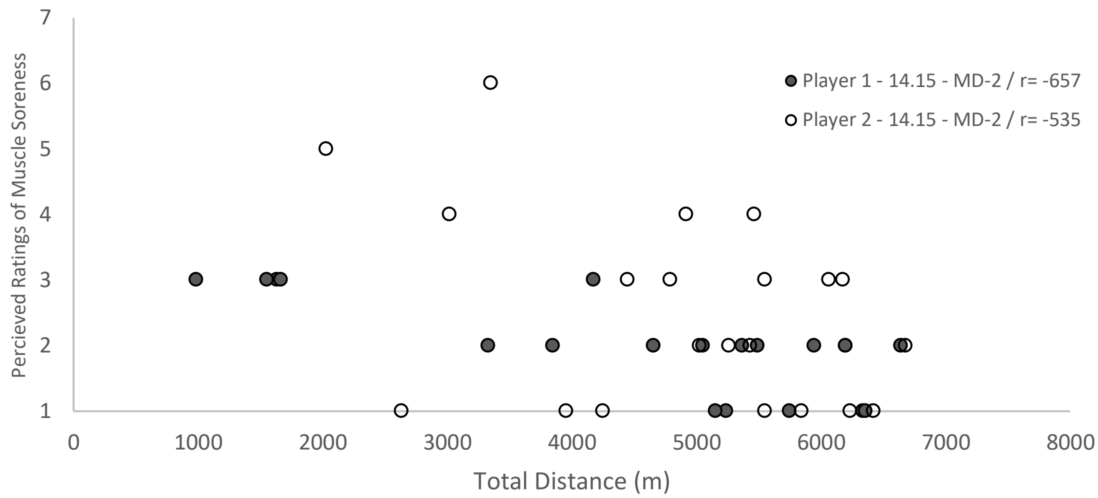

Figure 2 –Association between pre subjective ratings of muscle soreness (AU) and Total distance (m), Player 1 – *r*=-647; Player 2 – *r*=-534. A soreness rating of 7 represents an approximately moderate level of MS. Negative associations show in general some individual players will cover more distance when reporting lower muscle soreness ratings prior to training.

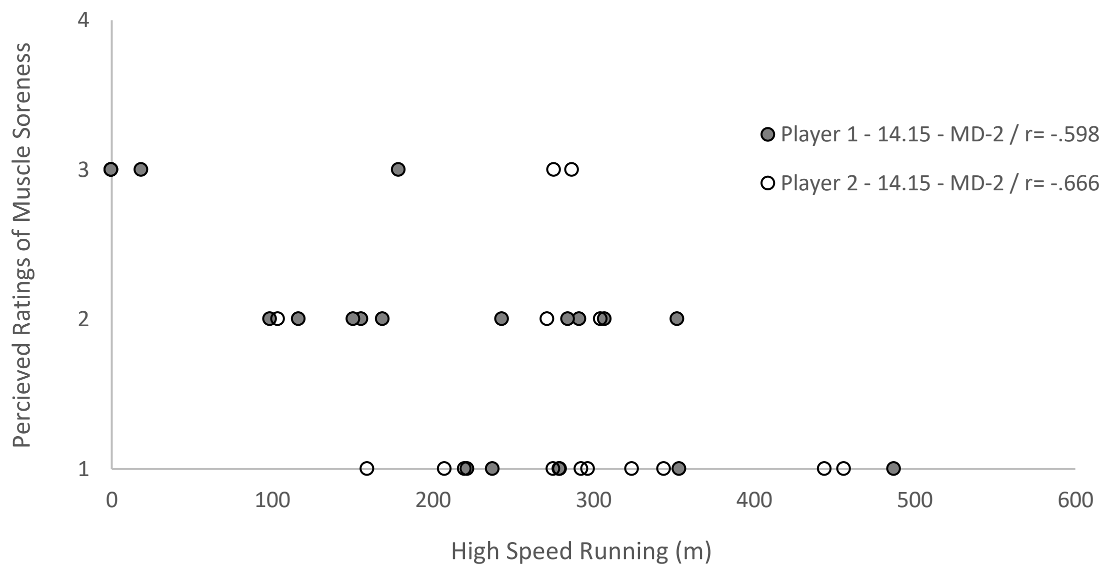

Figure 3 – Individual perceived ratings of Muscle Soreness associated with High Speed Running (m) 2014/15 season. A soreness rating of 3 represents approximately a mild level of MS. Reporting of a higher rating of muscle soreness shows that a certain individual may decrease their HSR output.

Significant negative associations between high-speed running and pre-training ratings of muscle soreness were found within 25% of players. Moderate to strong associations are shown within two players illustrated in figure 2, and further analysis at an individual level suggests that higher ratings of muscle soreness prior to training can decrease HSR distance.

4.2.2 Post Training Subjective Ratings

Further analysis at an individual level during the 2013/14 season highlights that 50% of players exhibited a moderate to strong association. Figure 4 displays examples of the two strongest associations found within the group during both seasons. Each graph presents one player from each season.

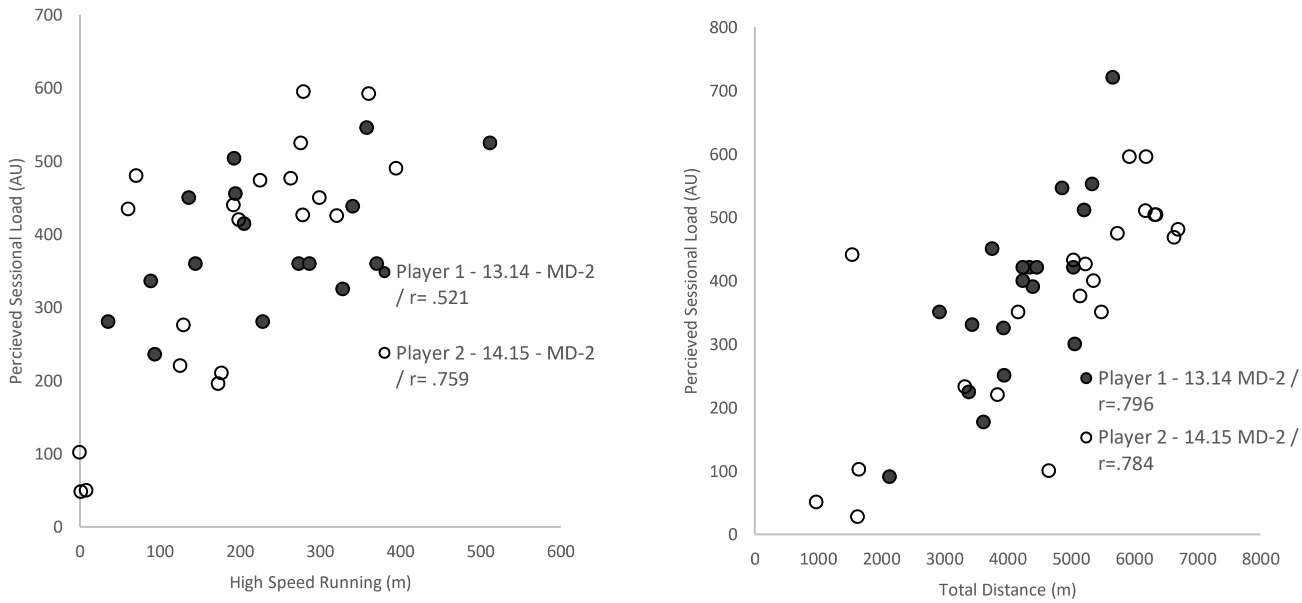

Figure 4 – Individual player associations for perceived sessional load (AU) and High-speed running (m) and total distance (m) during 2013/14 season and 2014/15 season. Both increases of TD and HSR result in increases of perceived post training sRPE.

4.3 Squad & Individual player case studies

4.3.1 Squad Case Study

Firstly, after examining the two separate seasons analysis was conducted over a combined two-season period at squad level. When analysing the two periods separately there were no moderate or strong relationships found between pre-training subjective ratings and performance metrics within training. This also appears when examining at the squad over the whole 60-week period.

However, when then analysing post training perceived markers and GPS metrics over the combined two season results are similar to the two separate in-season periods. Significant relationships were found between sRPE and TD also DSL (see Figure 5 & 6). However, no significant findings where shown in HSR. This may be because a second 35-week period of data collection was included. This was because of improved compliancy from the players, during the second season having greater compliancy will support the first seasons findings if similar. This has been shown within figure 5, the second season is making the relationship stronger. This supports the strength of the findings made during season 1.

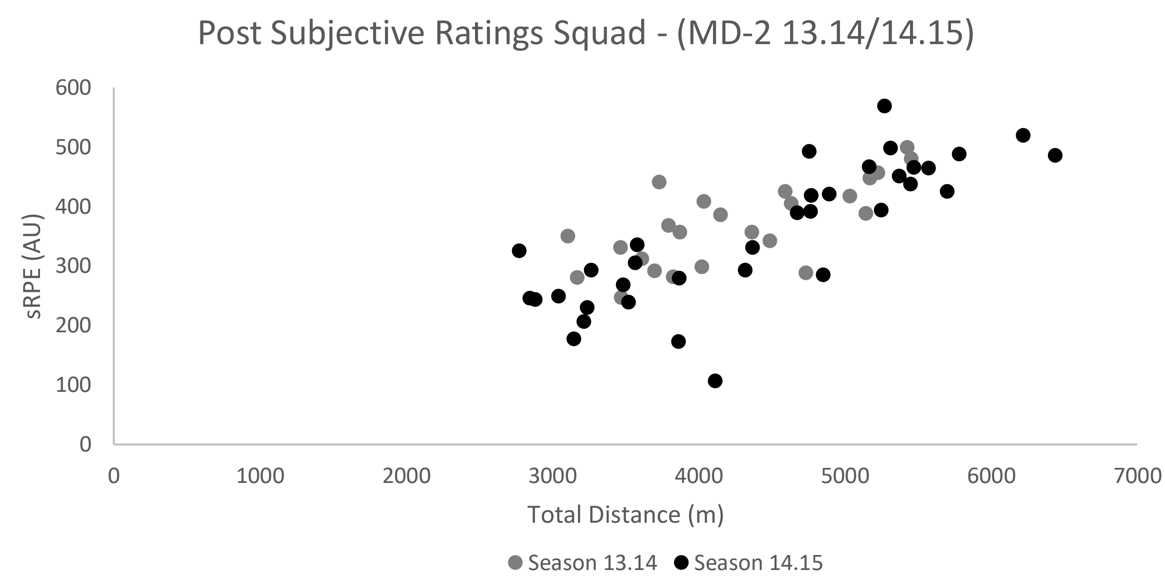

Figure 5 – Squad associations between sRPE (AU) and Total Distance (m) over a two-season period. Significant relationships are found as TD increased during a session so did sRPE.

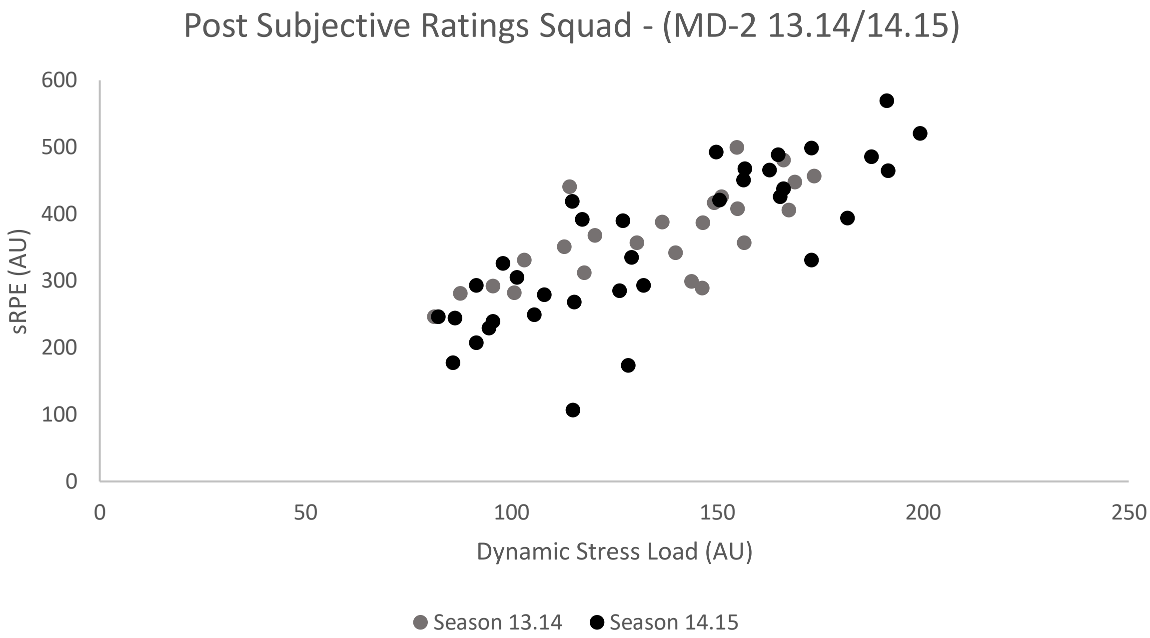

Figure 6 – Squad associations over a two season period between Dynamic stress load (AU) and sRPE (AU). Increase in dynamic stress load (AU) led to increases of sRPE (AU)

4.3.2 Individual Case Study

Over two in-season periods, there were only a certain number of players who completed both seasons. The authors wanted to make sure when analysing the data, it was expanded to make sure every part was examined, this was not just too examining one season separate to another in addition combine both season for individuals and to see if it does take a longer period of data collection to see trends. This will either support or findings already made by making results stronger between correlations or that extra work is needed to delve deeper into the data analysed. It was anticipated to back up findings from the results found within the second season; two players examined who had shown significant findings in the season were majority of results came from (14.15). The nine correlations were examined in the two case studies with increased amount of data with the combined two seasons.

Different results were discovered between the two players examined. Player 1 with the two seasons sets of data combined showed a higher significance of correlations between muscle soreness and total distance (Appendix A.7).

Moreover, when player 2 had their two sets of data combined it led to a significance across all metrics decreasing (Appendix A.7). Such differences within the two players findings may present issues of adherence. The difference in the results back up suggestions of possible adherence issues within the first season of data collection. As this study was completed in the field, the adherence eventually grew with the protocol over into the second season where most meaningful results were found. In addition, when a player has a small number of data points within one of season, when combining this with another season set of data this can increase variance of the data. However, it still can show significance but just not as strong compared to when less data points.

Chapter 5 – Discussion

The aim of the present study was to investigate the associations between subjective wellness markers, correlated with GPS performance, throughout two competitive seasons in the English Premier League. The current findings suggest that readiness to train questionnaires analysed at a squad level prior to training may not provide information that would be related to subsequent training performance. However, when analysed at an individual level across all players, increased ratings of muscle soreness where correlated with a decrease of HSR, TD and DSL for certain individuals have been identified as potentially impacting training outcomes (Figure 3 and Table 3). Conversely, when analysing sessional RPE post-training, strong correlations with GPS performance metrics were presented. This information may be beneficial to sport science and coaching staff to influence change within a player's physical performance for the following training session and training plan for the week. The main rationale for collecting wellness markers is to allow the practitioners to start a conversation with the athlete, as it may not always be physical exertion that is the main cause of increased wellness ratings. A practitioner should want to understand more context, as it may be a poor sleep, or the athlete may be suffering from illness.

Within the literature there have been different methods and periods of the season used to collect and analyse pre-and post-training subjective data. Pre-season (Bucheit et al. 2013 & Gallo et al. 2016), in-season (Thorpe et al. 2015, Gastin et al. 2015, Haddad et al 2015, Montgomery et al. 2013 & Malone et al. 2018) and both pre- and in-season periods (Moalla et al 2016) have been investigated. Typically, during a pre-season period there is a focus to improve player's fitness levels and increase training loads, resulting in higher demands experienced by the body. In turn, you would see an increase rating of wellness scores (Bucheit et al. 2013, Gallo et al. 2016). Therefore, an in-season period of data collection was chosen, to examine when players are within competition do pre-training wellness scores influence performance.

Results from Thorpe et al (2015), identified a squad association between total high intensity running distance and fatigue. However, in the present study there was no squad-related associations of prior subjective ratings and performance metrics via GPS analysis. A possible explanation of this is the significant difference in data collection periods. The present study collated data from two competitive seasons, which accounted for 60 weeks. This is a stark contrast to Thorpe et al (2015), whereby data was analysed approximately over a 2-week period. The large amount of data collected within the present study could have provided a greater variation of data that reduces its sensitivity when examining the data, it being significant enough to examine, resulting in conflicting results. However, this may not be the case as examining longitudinal studies allows practitioners to understand the variability of the data. As when making decisions on smaller data-sets may not be of any use to practitioners without understanding how the data can vary overtime (Gregson et al 2010). Moreover, pre-subjective rating scores were only compared with total high intensity running, whereas increased amount of specific metrics e.g. total distance (volume), high speed running (High intensity) and dynamic stress load (general body loading) were used as correlations within the present study. In doing this the aim was to demonstrate which metric may correlate with pre-subjective wellness. Pre-training wellness has been strongly correlated within an individual's total distance covered in similar research that has examined pre-subjective correlated with sRPE (Moalla et al. 2016). However, recent evidence supports the use of pre-training wellness measures over a longer period. (Malone et al. 2018) examined two elite soccer teams during a one season period only examining training physical data. Similar findings of pre-subjective wellness ratings were discovered between player load values, a metric very similar metric to dynamic stress load. However different significant findings were discovered compared to prior studies from Thorpe et al. (2015). As high-speed running was significantly correlated with pre-subjective correlations, this may be have discovered differently to the present and Malone et al. (2018). This was due to a larger number of games involved within the study throughout the season compared to only 2 games within Thorpe et al (2015). Moreover, when looking at player 1 over the two-season period case study there are larger improvements in significance across the whole selection of metrics. If this was added with data from another training day within the week or added games loads the authors may discover similar findings as Malone et al (2018). However, this would come with increased variance of physical metrics over more than one training day. Intensity of training sessions and outputs form these would then change and also increase the variance of the data collected.

MD-2 was chosen as the only training day that would be analysed to minimize variability and outliers within the data. Several studies have presented with different variations for several reasons. Thorpe et al, 2015 reported a 115% day to day variation in total high-speed running distance between every training session and games during a 17-day period. However, by selecting a specific training day or a specific part of a training session it can reduce the variation over an extended period Gallo et al (2015). From the skilled based sessions represented with Australian Rules football a lot of contact body work and grappling based skill sessions would have taken place; this movement would influence the player load metric derived from the accelerometer in the GPS. Moreover, Haddad et al (2013) only examined within their study effects on perceived wellness on a sub-maximal 10-minute running performance test As this test is a sub-maximal test this should not stress the player physically, and you would not expect to see pre-training wellness scores affecting a small low-level part of training. This supports the findings and reasoning behind looking at a whole of a training session during the present study. Appendix A.2 presents the variability in training days and there is a clear difference in actual days trained (for example, see MD-3 compared to MD-2). This inconsistency is not shown when examining MD-2 training day over a longer period, as total number of training days may differ week to week with the games schedule.

Los Arcos et al, (2014), investigated the relationship between post-training subjective measures and physical performance. They reported correlations between sessional RPE and physical performance tests (15 m sprint and counter movement jump). They also found that an increase in the cumulative load of sRPE negatively influenced performance over a 9-week training cycle. This data highlights the need to analyse the RPE post-exercise, which supports the authors findings of that sRPE is positively correlated with increases in TD, HSR and DSL. Therefore, these metrics need to be closely monitored to ensure that the cumulative increase in TL that occurs throughout the season and does not affect performance. However, Los Arcos et al, (2014) did not use GPS data analysis during their training cycle, so the content of the training sessions was unclear. To the author's knowledge, there is limited published literature that has examined individual ratings of MS and FAT associated with GPS metrics within elite level soccer, although there have been studies within the Australian Football League (AFL) (Buccheit et al. 2013, Gastin et al, 2013). During individual player analysis over an AFL 27 week in-season period, reduced perceived wellness and increased fatigue was associated with a decrease in physical performance, measured by TL, perceived exertion and heart rate. The present investigation discovered similar findings of FAT and MS, associated with the physical performance levels derived from GPS. However, with fewer associations, this may be due to the different measure of physical performance, in comparison to the previous study, which only used internal measures of heart rate and perceived level of TL (i.e. sRPE) (Gastin et al, 2013). The present study also showed to have used external measures of physical performance from GPS analysis. An additional study examined pre-training subjective markers of readiness to train during a preseason training camp. They reported that increased levels of FAT and MS during this training period were due to the increase in intensity of training. The authors concluded that subjective markers of wellness are the best measure for training response from players within a training camp, although the wellness score is a multiplication of an index of score ratings from sleep quality, muscle soreness, fatigue, stress and general mood (Buccheit et al. 2013). The present study investigated separate ratings of FAT and MS, which provides the user with the ability to distinguish a more in-depth analysis on which specific ratings may influence GPS measures. Examining the physiological responses of pre-subjective ratings in muscle soreness and fatigue. In addition, the use of an index combining all wellness scores could give practitioners a general daily wellness score, with the option of delving deeper into the player's data to look at individual subjective ratings if necessary. Unlike pre-training subjective measures which found relationships between certain individual players and not on a squad analysis, the current data illustrates that post training subjective measures have moderate to strong associations with both squad and individual analysis (Table 2). This data is supported by several other studies (Thorpe et al 2015, Malone et al. 2018, Gallo et al. 2015, Gastin et al. 2013, Buccheit et al. 2013).

Casamichana et al (2013) investigated the association between sessional RPE and TD and HSR in 28 semi-professional male soccer players in the Spanish third division. This study reported strong and moderate relationships for sRPE and TD and HSR respectively. These results are similar to the present study (Figure 5). Similar to the present study, a study of twenty-two elite Premier league players over an entire in-season period examined associations between RPE, sRPE and GPS metrics (HSR, Impacts, Accelerations) (Guadino et al. 2015). The external load measures which are the objective measures of work performed by an athlete during training, measured by time-motion analysis and Global positioning system parameter, different to internal load markers of physiological responses to the physical output measured but internal markers of heart rate, blood lactate and oxygen uptake. The external load of HSR, impacts and accelerations were shown to be moderately predictive of sRPE. These results can be informative for coaches and practitioners. As when planning intensity of sessions, the enhances of training prescription (by supporting with more objective evidence). Example of this can be during pre-season period where double sessions take place if the morning sessions was too hard or not hard enough as planned, from the RPE scores given you would be able to adapt the afternoon session where needed too to meet the physical requirements set. This allows increased detail to the planning. Results found, both in the present study and Gaudino et al (2015), provide considerable evidence of how sRPE is a strong measurement of physical performance levels within elite level soccer. With the present study examining TD, HSR and DSL over a longitudinal period, this suggests that with several different GPS metrics, sRPE can be an indicator of physical exertion of training. These findings are similar to the investigation with Australian A-League players. Moderate and strong relationships were all found in associations between TD, lower speed running (<14.4 km/h), high speed running (>14.4 km/h), very high-speed running (>19.8 km/h) and sRPE (Scott et al. 2013), with the present study showing further support for sRPE over prolonged periods within soccer.

An observation that has been reinforced in the present investigation is that TD is strongly associated with sRPE at an elite level (Gaudino et al, 2015, Scott et al. 2013). However, within soccer, TD probably should not be the definitive metric used to decide on physical performance or load, as it can be regarded as a measure of training volume and not necessarily a measure of training intensity. Additional intensity metrics within the GPS data such as HSR, acceleration, deceleration is also informative and related to fatigue and player loading indices. A weighted combination of some of these metrics might provide the best insight into physical performance and training intensity. It would be more informative to break the TD into distances, covered within the different speed thresholds, to identify the distances at the higher speeds. TD may be better utilized as a marker of training volume over specific training cycles, to enable examination of any fluctuations within training volume week to week or within the periodised cycle. A metric of interest may be DSL. This provides information on the specific weight of step impacts of an individual and, when used as a within-subject measure, may identify periods of increased loading.

5.2 Limitations

Over the two separate in-season periods you can see development within the study, where it was discovered it was affected by adherence within the subjective rating scale to assess wellness incurred within the 2013.14 season whereas we had a collected 295 wellness questionnaire answers from 450 session which gave a compliancy rate of 65% This was a another reason that we chose to use the first season of data as a pilot season. These issues were improved between the 2013/14 season (25 weeks) and 2014/15 season (35 weeks). This may also be the case within the individual analysis, whereby unexpected results have been identified. However, these individual abnormities may also be due to a lack of engagement from the players. Moreover, there was little information given to the players about the definitions of rating scores in the middle of the scale. A more defined scale like the RPE scale for MS and FAT as mentioned within the present study we chose a Likert scale of 1-10 as for players this was easier to relate to from already using this scale for the RPE. This has been beneficial for the players for understanding and education. It would now be next steps to then add extra detail to what each level would represent similar to the RPE scale. could improve player's education and understanding of their scores. Due to repetition of the monitoring protocol, daily scores should not be adopted, but scores such as MD+2 and MD-2 should be used for days which are only important for recovery. Recent publications have shown development within the area of subjective ratings on what could provide more meaningful information to coaches and practitioners. This has come from the use of z-scores within the research (Gallo et al. 2015, Malone at al. 2018 & Govus et al. 2017). In addition to examining what relationships have been found between pre-training, subjective ratings and physical performance. Examining in more detail variance of individual players of why differences occur would be valuable for future research. The influence of wellness Z-scores have also been examined. Specific increases or decreases of an individual's wellness z-scores are related to either a specific increase or decrease within physical performance. This provides another deeper level of analysis for the planning field training sessions or setting targets for individuals based on wellness z-scores. To develop these findings even more in the future, influences of changes in wellness scores on the effect on physical performance should be examined. Moreover, is their scope to analyse trends and if there is a relationship over time between wellness z-scores and soft-tissues injuries.

5.3 Practical Implications

Results over the two in-season periods suggest that pre-subjective ratings do not provide any information on physical performance within training. This would insinuate that it could give practitioners inadequate data to report to coaches and sport scientists. However, convincing evidence suggests that sRPE can be a quick feedback tool to gauge physical performance during training within elite level soccer. It allows sport scientists and fitness coaches to plan physical training intensities for each individual player and avoid the risk of training overload, which can be beneficial to the coach and medical team. Limitations to this study include positional differences of players, which might account for variance in the workload within the sessions. In addition, training content throughout the season may differ from week to week, despite attempts to reduce this by selecting MD-2. Where it's likely that education of the players, in terms of how to consistently and accurately rate their muscle soreness and fatigue levels, varied between squad members. This could have altered the current dataset to some extent; an aspect which will hopefully be more controlled in future work.

Chapter 6 – Conclusion

In conclusion pre-training subjective wellness ratings at a squad level do not provide a good indication of physical performance levels during the next training session. There has been evidence to show when examine wellness questionnaires it must be on an individual level, with there being many factors influencing a wellness score. Moreover, results provide increased support of evidence for the use of subjective ratings post-training (sRPE), with significant relationships discovered across all GPS metrics.

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Appendix

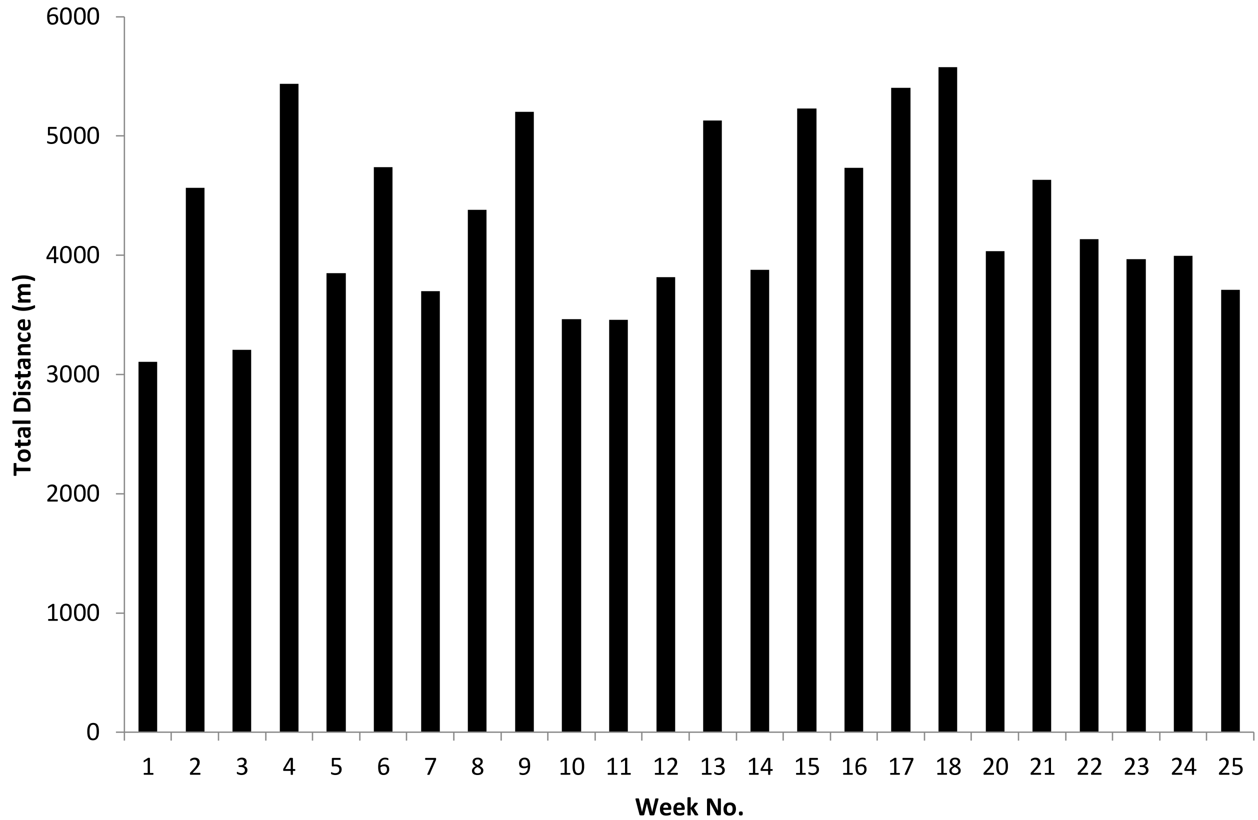
A.1 Nine Correlations Conducted

Metric A		Metric B
Total Distance (m)	⟷	Muscle Soreness (au)
Total Distance (m)	⟷	Fatigue (au)
Total Distance (m)	⟷	Perceived Sessional Load (au)
High Speed Running (m)	⟷	Muscle Soreness (au)
High Speed Running (m)	⟷	Fatigue (au)
High Speed Running (m)	⟷	Perceived Sessional Load (au)
Dynamin Stress Load (au)	⟷	Muscle Soreness (au)
Dynamin Stress Load (au)	⟷	Fatigue (au)
Dynamin Stress Load (au)	⟷	Perceived Sessional Load (au)

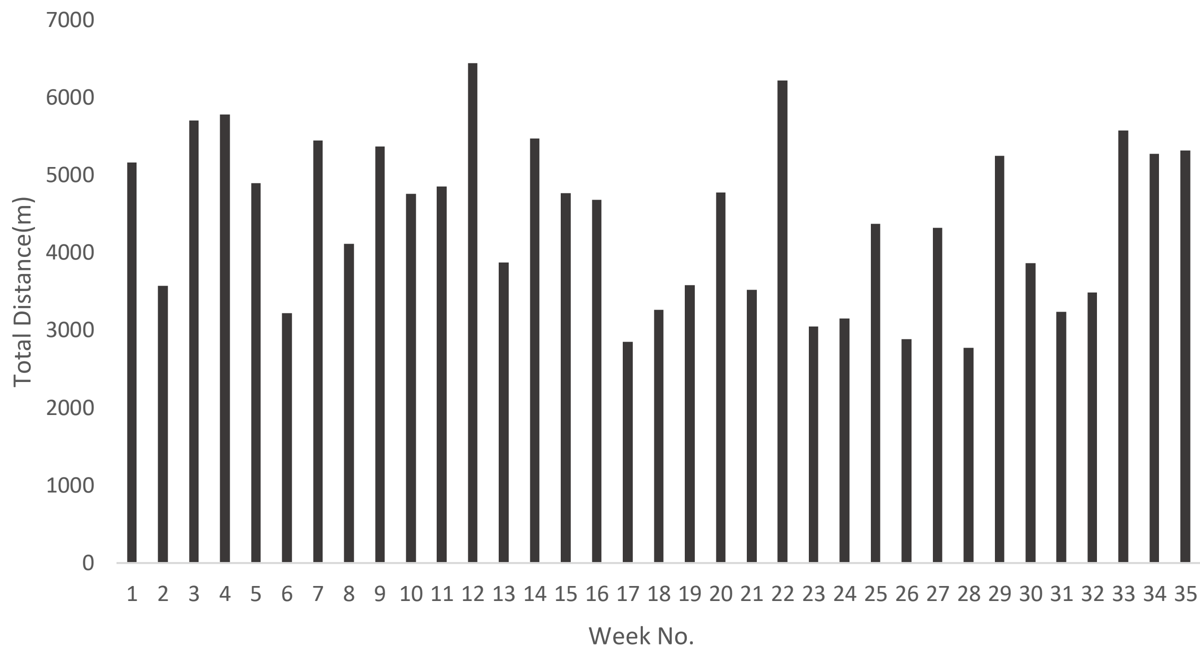
A.2Mean & SDs Squad MD-2 variables

Metric	Season	Mean	SD
Total Distance (m)	2013 – 14	4329	722
	2014 – 15	4426	1055
HSR (m)	2013 – 14	149	67
	2014 – 15	189	88
DSL (AU)	2013 – 14	123	26
	2014 – 15	134	35
RPE (AU)	2013 – 14	5.8	0.7
	2014 – 15	5.6	1.1

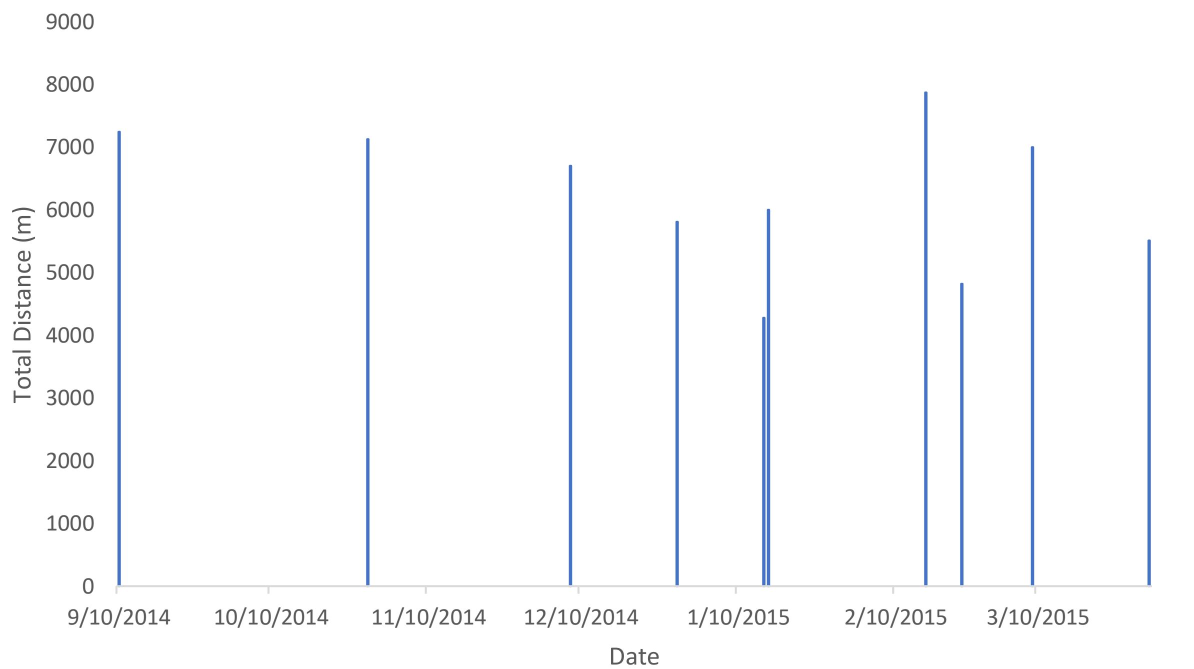
A.3 Figure Squad average total Distance



MD- 2 Total distance (m) during 2013/14 season; (Mean = 4328m SD ± 726m)

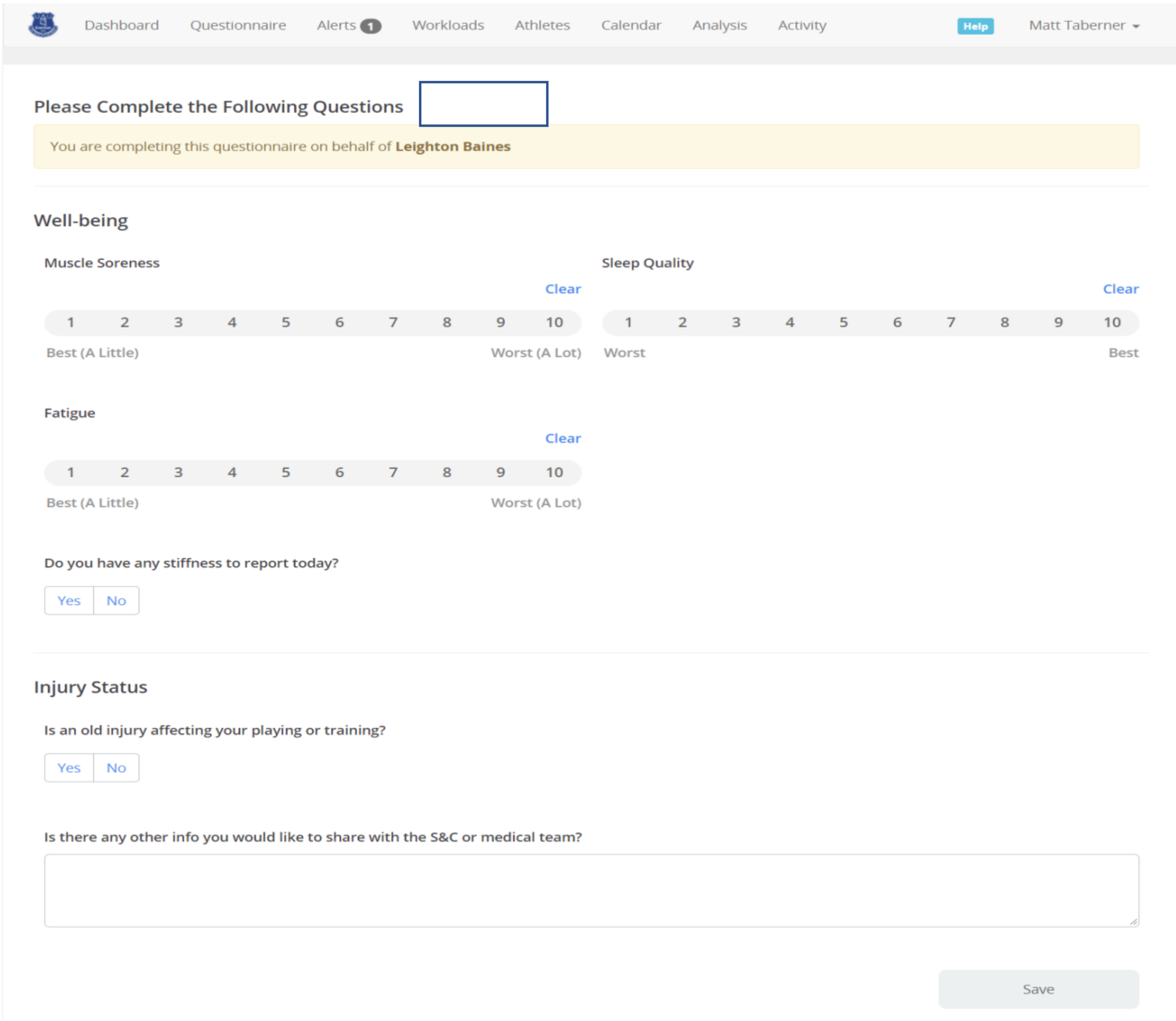


MD-2 Total Distance (m) during 2014/15 season (Mean = 4427m, SD ± 1055m)



MD -3 Total Distance (m) during 2014/15 season (Mean = 6236, SD ± 1090)

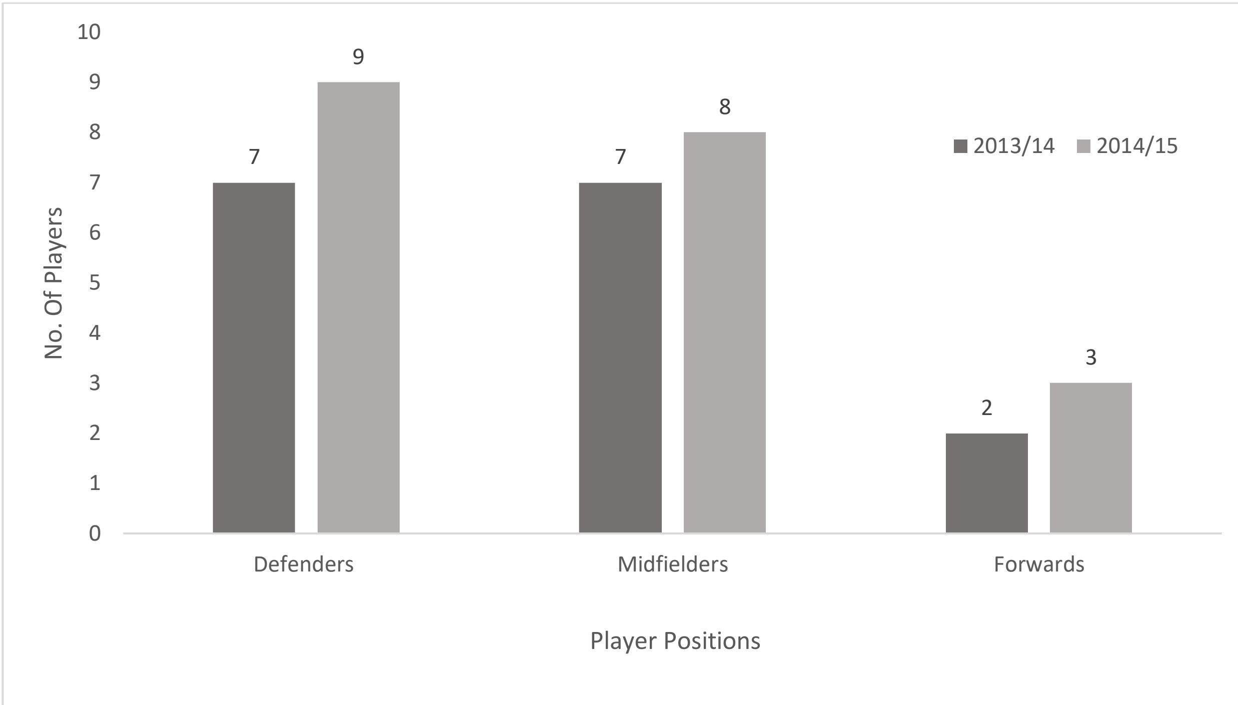
A.4 Perceived wellness ratings questionnaire



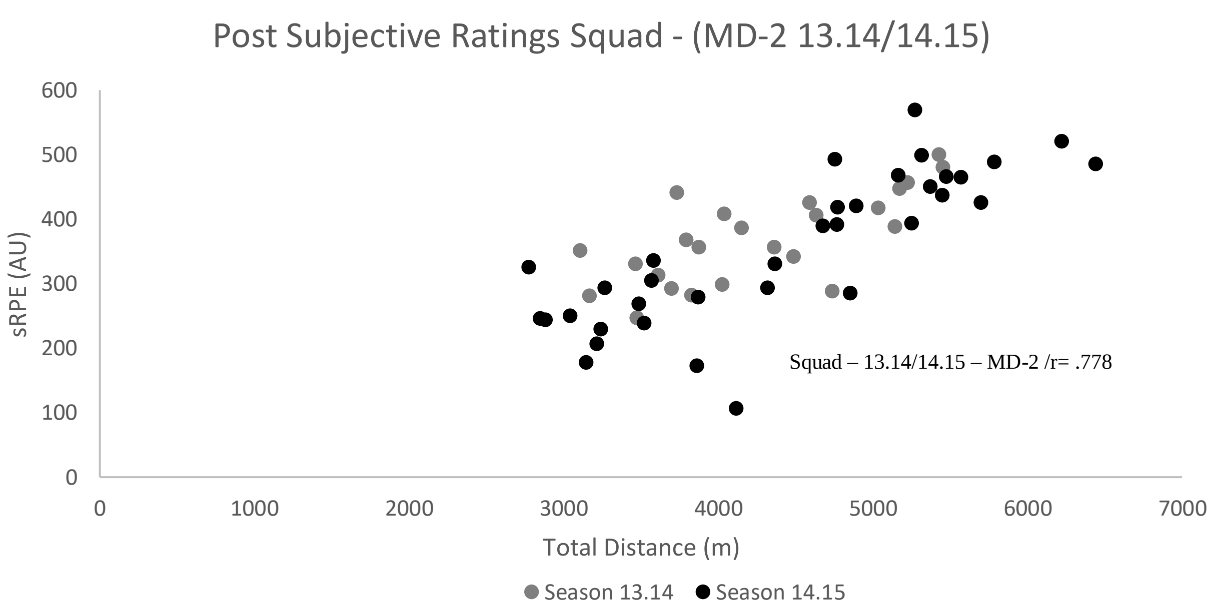
A.5 Rating of perceived exertion scale

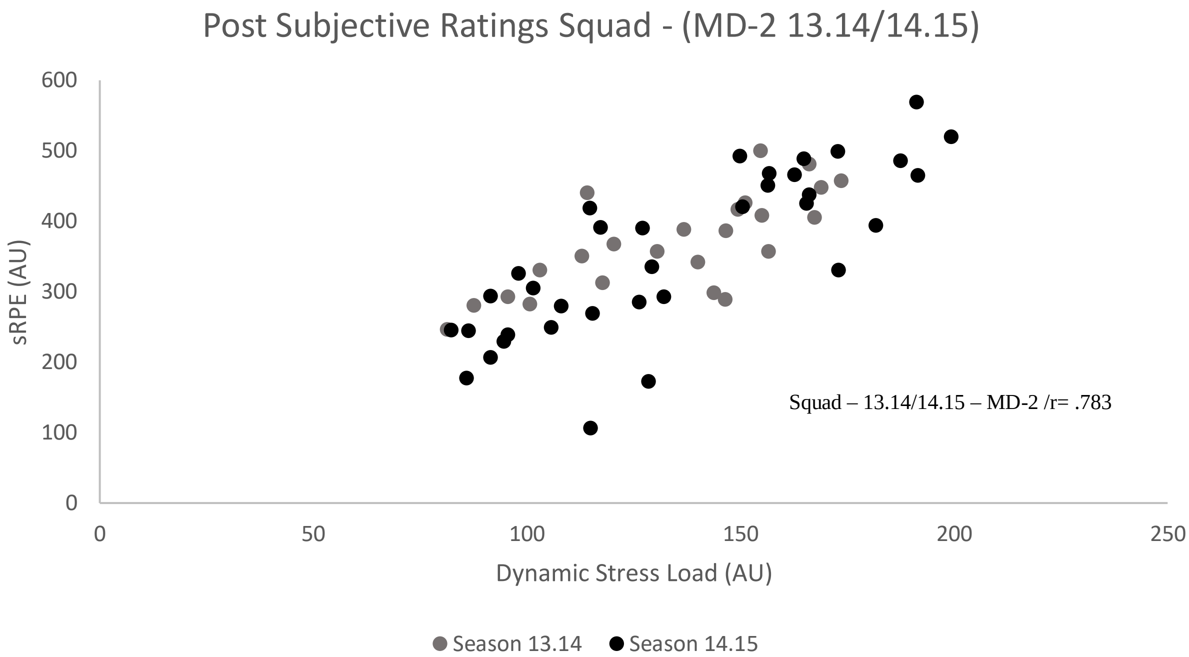
Rating of Perceived Exertion (RPE) Scale:	
0	**Rest**
1	**Really Easy**
2	**Easy**
3	**Good Sweat**
4	**Low Moderate**
5	**Moderate**
6	**High Moderate**
7	**Hard**
8	**Really Hard**
9	**Really, Really Hard**
10	**Maximal** **(90min Match)**

A.6 Player positions



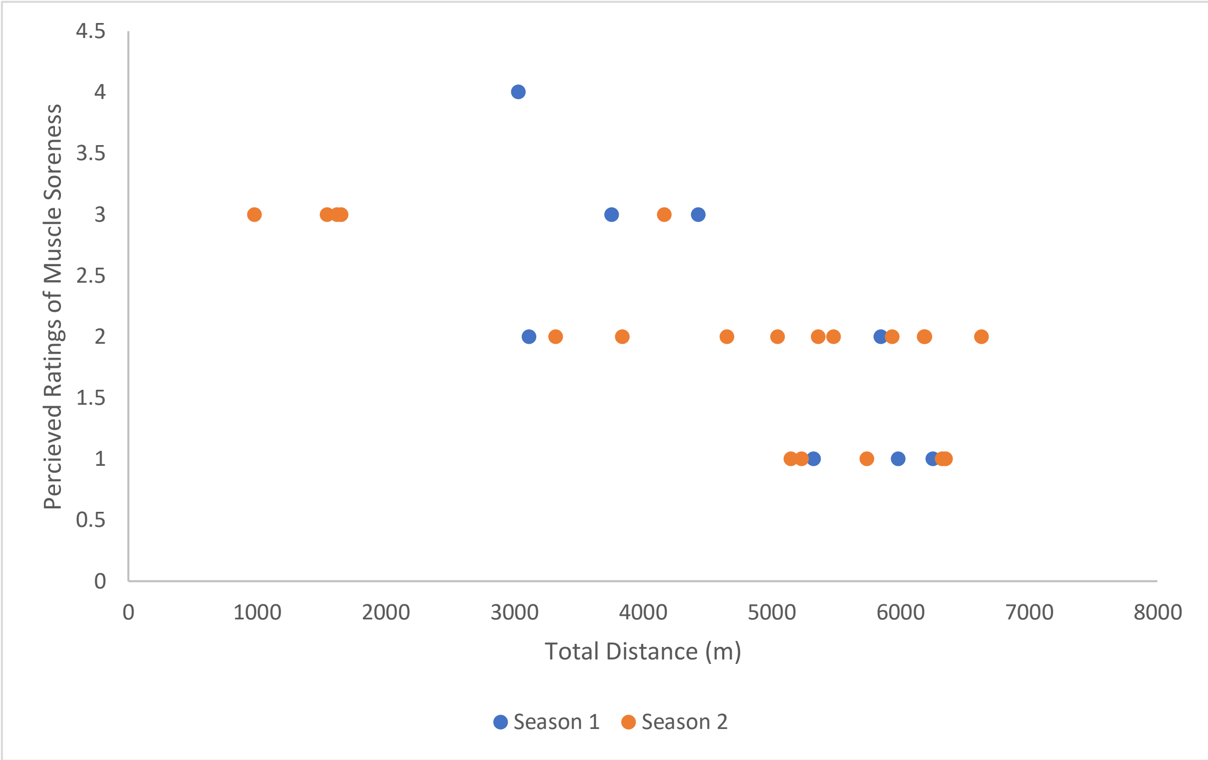
A.7 Squad Analysis over a two season period




Post Subjective Ratings Squad - (MD-2 13.14/14.15)
sRPE (AU)
600
500
400
300
200
100
0
0
50
100
150
200
250
Dynamic Stress Load (AU)
Squad – 13.14/14.15 – MD-2 /r= .783
Season 13.14
Season 14.15

A.8 Individual case study Analysis over a two-season period

Player 1



Player 2

	TD			HSR			DSL		
Period	MS	FAT	sRPE	MS	FAT	sRPE	MS	FAT	sRPE
13/14	.042	-	.574*	.339	-	.445	-.095	-	.604*
14/15	-.574*	-.706*	.924*	-.448*	-.666*	.667*	-.264	-.547*	.751*
2013-2015	-.408	-.497*	.876*	-.114	-.326	.598*	-.067	-.239	.736*

Results from player 2 over the two in-season periods and combined two season period r values. * = significant

No correlations found in fatigue during season 13/14 due to the same fatigue rating given for each time point.

A.9 StatSports Viper Pod Location

How the StatSports vest looks on a player. Located at the top of the trunk.

This image shows the location of the pod within the back of the vest. The pod sits in a pocket between the players shoulders blades.

Image of the StatSports viper pod and the components inside the viper pod.