Training Load Monitoring in Rugby Union

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List of Abbreviations

sRPE	Session Rate of Perceived Exertion
T	Testosterone
C	Cortisol
TC	Testosterone to Cortisol Ratio
GPS	Global Positioning Systems
TMA	Time Motion Analysis
ICC	Intra Class Correlation
CV	Coefficient of Variance
HDOP	Horizontal Dilution of Position
HSRM	High Speed Running Metres
VMax	Maximum Velocity
MAS	Maximum Aerobic Speed
YYIRT1	YoYo Intermittent Recovery Test 1
ELISA	Enzyme Linked Immunosorbent Assay
ANOVA	Analysis of Variance
TL	Training Load
BM	Body Mass
GS	Groin Squeeze
CMJ	Counter Movement Jump
KTW	Knee to Wall
ATL	Acute Training Load
CTL	Chronic Training Load
ACWR	Acute to Chronic Training Load Ratio

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Introduction

Training is a deliberate and focused activity undertaken to improve performance or some component of performance in a given sport or event, (Ericsson et al*., 1993;* Smith, 2003). Training is essential for successful competition and participation in sport. Due to the different skills and physical capacities that are essential for success in any given sport, the training for that sport will consist of many different modes, (Smith, 2003). As such each component of training will have a different outcome measure; be it improvement of a technical ability or an improvement in physical performance. In field sports, a substantial portion of training time will be committed to improving technical skills, (William and Hodges, 2005), as well as physical capacities, (Gabbett, 2004).

Physical training is the stimulus for improvement in an athlete's physical, physiological and performance characteristics, (Impellizzeri et al., 2005). The volume and intensity with which an athlete or player trains to develop skills or physical capacities is their training load and it is important that this is quantified by coaches and performance staff to ensure that the athletes are ready to compete and perform, (Halson, 2014). It is well established that elite athletes need to train at high intensities and with high volumes where appropriate in order to develop both skills and physical qualities for their sport, (Smith, 2003). Training load is the stress or strain placed on an athlete when training or competing and training load can either be internal or external;

external load is the work done by the athlete, (Wallace et al., 2009), and internal load is the athlete's individual physiological stress or response to the work done.
Training load can be the stress placed on an individual in a single training session or over a training period which can be manipulated by athletes, coaches and support staff involved when designing, monitoring and implementing training programs, (Halson, 2014). "The relationship between training load injury, fitness and performance is critical", (Gabbett, 2013). There has been a lack of consistency regarding the definition of training load. Quarrie et al., (2016), contend that training load should be defined as all stressors and demands placed on players in preparation for competition. This compromises all sport-related and non-sport related inputs.

As previously stated, training load can be considered as either external or internal. External load is the work carried out by an athlete independent of their physiological characteristics, (Wallace et al., 2009). The external load may be total distance run, weight lifted or the number and intensity of sprints, jumps or collisions, (Impellizzeri et al., 2005). The internal load is the physiological and psychological stress imposed by or as a result of training, (Halson, 2014). So, while two people may be exposed to the same external load their internal response may be very different, a trained runner and a sedentary adult could both run 1 kilometre but despite both being exposed to the same external load their internal response could be very different, (Gabbett, 2016). The sedentary adult could find it much more psychologically and physiologically taxing. Due to this difference in internal response to external training load it is important to have valid and reliable measures of internal training load, as it is this relative physiological stress which is the stimulus for training induced adaptations, (Impellizzeri et al., 2004).

At the moment, there are many methods for monitoring both internal and external training load. Internal training load can be measured subjectively, for example, by use of session rate of perceived exertion (sRPE), (Foster et al., 2001). Internal training load may also be measured by use of subjective measures such as testosterone (T), cortisol (C) and their ratio (TC), (Handziski et al., 2006). External training load can be measured objectively using power output in sports like cycling, (Jobson et al., 2009), but this type of monitoring is practically difficult for football codes such as rugby union due to the use of equipment needed. Athletes involved in team sport are exposed to a variety of different external loads such as field-based skills training, on feet conditioning and resistance training, (Halson, 2014). As such there are different methods to monitor each; resistance training may be measured using tonnage, volume, intensity or time under tension, (Hiscock et al, 2015). However, the external training load during sport specific training may be more difficult to quantify.

External training load may be monitored using Time Motion Analysis (TMA), and can be used in team sports to determine metrics such as distance covered, velocity, direction of movement and number of collisions, (Dwyer and Gabbett, 2012; Roberts et al., 2006). External training load can also be measured using micro technologies such as Global Positioning Systems (GPS), (Coutts and Duffield, 2008). The relationship between the external training load and the physiological response (internal load) needs to be considered when designing a training program to optimize performance, (Borresen and Lambert, 2009). Practitioners need to also be aware that the relationship between a given measure of internal load and the external training load can vary with the training mode. For example, the extensive rest periods in skills and speed training sessions may reduce the perceived exertion associated with that session, (Scott et al., 2013). It has been proposed that a combination of internal and external load measures need to be employed and that the training mode needs to be considered when deciding on what training load measure to use, (Weaving et al., 2014).

Training load may also be measured objectively or subjectively, (Saw et al., 2015). Subjective measures of training load may be self-reported by athletes as perceived physical and psychological well-being, through wellness questionnaires and sRPE for training sessions. There is research to support the use of subjective measures of training load response and due to their ease of implementation and relative low cost they are valuable tools, (Saw et al., 2015; Meeusen et al., 2013). Objective measures of training load response include physiological, biochemical and performance testing. Performance is considered to be the best indicator of physical and physiological response to training, however, some performance tests such as VO2max would be impractical to test athlete's performance daily, (Currell and Jeukendrup, 2008). Hormonal markers have been proposed to be used but findings may be inconsistent due to factors such as the influence of circadian rhythms, nutrition and hydration status, psychosocial factors and exercise protocols, (Hug et al., 2003). There is further research needed to understand how the different types of measures interact and how they may be affectively integrated into applied practice, especially in the context of the mixed methods approach used in many sport settings, (Saw et al*.,* 2015). This study will determine the relationship between several objective and subjective measures that may be used in training load monitoring and how they may respond in relation to each other. This study will aim to determine if training load measures may change in relation to each other over the course of a period of competition and how they may change in relation to each other.

The validity and reliability of the different measures is also of importance. Salivary analysis of athletic populations for the determination of hormonal responses has become widely used in research and enzyme-linked immunosorbent assay (ELISA) is the most commonly used method, being considered the best method under reasonable conditions, (Coad et al*.,* 2015). Salivary measures of cortisol have been shown to be a valid and reliable measure of serum cortisol (r = 0.874, $p < 0.001$), (Obminski and Stupnicki, 1997). It was observed by Rudolph and McAuley, (1998), that there was a positive relationship between session RPE and salivary cortisol, (between r = 0.36 and 0.38, $p < 0.05$). Gaviglio et al., (2014), showed that salivary testosterone to cortisol ratio can be used as a predictor of success in rugby union matches with the study showing significant midweek differences ($p < 0.001$) before winning games when compared to losing. Cardinale and Stone, (2006), stated that there was a significant positive relationship between testosterone and jump height (r = 0.61, $p < 0.01$). As jump height has shown a strong correlation with sprint speed over 10 metres (r = 0.72, $p < 0.001$) and 30 metres (r = 0.60, $p < 0.01$), (Wisloff et al*.,* 2004), it is worth considering measuring testosterone as a marker of potential performance. Research by Crewther et al*.,* (2009), also indicated a correlation between salivary testosterone and cortisol to neuromuscular performance as measured through running velocity, squat jump, bench throw and one repetition maximum for bench press and box squat ($p < 0.05$). They propose that due to the importance that these physical capacities hold in rugby union that there would be merit in monitoring these in rugby players. However, Hayes et al*.,* (2015), suggested that the effect of exercise on hormonal response may vary depending on the training modality.

Foster et al*.,* (2001), stated that session rate of perceive exertion (sRPE) has been shown to be a reliable indicator of the internal, physiological response to training ($p < 0.05$). Session RPE is a self-reported indication of intensity of a training session and is reported in this case on a scale of 1-10. Training load is reported from this in arbitrary units (AU) and is the session RPE multiplied by the time of the session. Session RPEs demonstrate a strong relationship with training impulse (TRIMP) ($p < 0.05$), which uses the heart rate reserve and duration of exercise to determine the intensity of the exercise. While it was developed for use in endurance sports it has been validated for use in team sports, (Impellizzeri et al*.,* 2004), with a correlation of $r = 0.71$ ($p < 0.001$) found between TRIMP and sRPE in soccer players. Lambert and Borensen, (2010), suggested that session RPE in collision sports such as rugby league may not account for the physiological stress of frequent collisions and the high-intensity, intermittent nature of the sport. However, Lovell et al*.,* (2013), suggested that as part of a combination of measures it can be used effectively in these sports. It has been shown in professional rugby union players that training load as measured by session RPE can be indicative of likelihood of injury, with high training loads having a strong correlation with injury rates, (Cross et al*.,* 2016). It was suggested by Gabbett, (2016), that large fluctuations in weekly loads as measured by session RPE, may be associated with an increased likelihood of a player getting injured.

There are several methods of monitoring the external training load in team sport such as quantifying the movement demands of training and match play. Traditionally, this was completed by way of video-based time-motion analysis (TMA), however, this was a time intensive process whereby only one player may be analysed at a time and it depended on subjective interpretation of the activities, (Dwyer and Gabbett, 2012; Roberts et al*.*, 2006).

Recently there has been a growing body of research using global positioning system (GPS) data to quantify the movement demands and activities involved in sport, (Reardon et al., 2015; Gabbett, 2013; McClellan et al., 2011.). It was demonstrated by Johnston et al*.,* (2014), that GPS units that sample at 10 Hz were valid and reliable for measuring sport related training activities, although the reliability with which these are reported varies from study to study. The accuracy of the GPS units can be affected by the speed of the movement. In a systematic review of GPS technology, Cummins et al*.,* (2013), showed that there was a greater measurement error when reporting speed over ~6 ms^{-1} (running speeds) when compared to walking speeds (~1.8ms^{-1}). Gabbett, (2013), also questioned the ability of GPS units and micro sensor technology to quantify contact loads in collision sports such as Rugby Union, with further research needed to validate these measures.

This study will determine the validity and reliability of GPS units to measure and report several rugby union related movement demands. This study will aim to determine their reliability by comparing GPS units when worn concurrently during a sport simulated trial and determine validity by comparing them to criterion measures; known distance, known number of collision and velocity as calculated by timing gates. This will lend further credence to the use of GPS technology in monitoring team sports.

There are also discrepancies in the way that data is reported using GPS technologies, (Reardon et al*.,* 2015), particularly around the area of speed thresholds and reporting of running distances at specific speed bands. The use of arbitrary speed thresholds for all players or athletes means that there may be an underestimation or over estimation of running distances at given speed thresholds depending on their individual maximum running velocity. The quantification of running distance at different thresholds is of interest due to importance of physical capacities like repeat sprint ability, (Nakamura et al*.,* 2017). The use of individual speed thresholds has been suggested as opposed to arbitrary to better describe positional and individual player running demands during a game, (Malone et al*.,* 2017; Nakamura et al., 2017; Reardon et al., 2015.). There is a need for consensus as even the individual thresholds prescribed for high speed running can range from 90% of maximum velocity, (Nakamura et al*.,* 2017), to 60% of maximum velocity, (Reardon et al*.,* 2015). This study will aim to determine if there is a physiological basis for the prescription of individual thresholds compared to arbitrary thresholds and which individual threshold of high speed running metres best reflects the internal response of athletes to training and may be used in practice and in further research.

The merits of training load monitoring and having valid and reliable methods for monitoring both internal and external training load are evident. They are essential in the scope of sports performance programs and should be utilised by strength and conditioning coaches and sport scientists to develop robust athletes, who can compete with minimised risk of injury and at the highest level. The aim of this study is to further the understanding of training load monitoring modalities in rugby union through the use of GPS technology, subjective measures of training load and objective measures of training load.

Aim

The aim of this study can be divided into three parts. Part one will determine the reliability and validity of 10 Hz GPS units for describing the movement demands of rugby union. Part two of the study will determine the relationship between internal measures of training load and individual or arbitrary definitions of high speed running metres. Part three of the study will determine the relationship between different objective and subjective measures of training load over the course of an 11-week international window in Elite U-20 rugby union players.

Objective

1. Determine the reliability and validity of 10 Hz GPS units for describing the movement demands of rugby union

2. Determine the relationship between internal training load and different definitions (arbitrary and individual) of high speed running metres in rugby union
3. Determine the relationship between objective and subjective measures of training load in Elite U-20 rugby union players

Hypotheses

Null Hypothesis

1. H_0: 10 Hz GPS units will not be valid and reliable for determining the movement demands of rugby union.
2. H_0: There will be no difference in relationship between internal training load measures and arbitrary or individual definitions of high speed running metres in rugby union.
3. H_0: There will be no relationship between any of the objective and subjective measures of training load in Elite U-2O rugby union players.

Literature Review

This section will review the current literature surrounding the training load measures employed in this study. It will also include an overview of the game of rugby union so that each of the measures may be examined in the context of the demands of the sport. The measures examined can be subdivided into objective and subjective with the objective measures being endocrine response, global positioning data, musculoskeletal assessment data and neuromuscular data. The subjective measures are session rate of perceived exertion and perception of wellness data.

Rugby Union

When devising a monitoring program for any sport or athlete it is important to understand the demands of the sport and to understand the goal of the monitoring system, whether it be to maximise performance or to minimise fatigue and its associated risks, (Gabbett et al*.,* 2017). The sport of rugby union is a full-contact team sport which is played over two 40-minute halves with a ten-minute half-time interval, (IRB, 2013). The objective of the game is to score more points than the opposition by passing the ball backwards and running or kicking the ball forwards into the opposition goal area and touching it down on the ground. Alternatively, points can be scored by kicking the ball between the goal posts and over the bar. Each team consists of 15 players, with playing positions being generally sub divided into forwards and backs. Positions can be further divided into props, hookers, second rows, back rows, scrum halves, out halves, inside backs and outside backs. Traditionally the backs are faster and more agile while the forwards are bigger and stronger, however, with the onset of professionalism in rugby union the game has become more physically demanding and the physiological and anthropometric characteristics of players across all positions have started to become more similar with forwards becoming faster and more agile and backs become larger and stronger, (Quarrie & Hopkins, 2007; Nicholas, 1997).

Rugby players cover an average of 6,953 metres (m) during an 80-minute (min) game, (Cunniffe et al., 2009), of which 420 m (6%) is covered sprinting. The average VO2max for players during a match was 80-85% (as determined using the HR-VO2max relationship) with a mean heart rate (HR) of 172 beats per minute (BPM). However, despite the increasing similarity between the positional subgroups there is still a positional variance between the players. Backs had an average work to rest ratio of 1:20 compared to forwards whose average work to rest ratio was 1:6, (Duthie et al., 2005). It was determined using time motion analysis that back row forwards spent the greatest amount of time involved in high-intensity exercise (1190 ± 241s) of all groups of players, whereas outside backs spent the least amount of time involved in high-intensity exercise (570 ± 91s), (Austin et al., 2011). The training for rugby union needs to simulate the demands of the game (as with all sports) and as such training should consist of periods of high-intensity activity followed by short rest intervals, (Duthie et al., 2003).

On average during a match the backs will perform more sprints than the forwards; backs performed 9 ± 4 sprints compared to 5 ± 4 sprint performed by the forwards, (Duthie et al., 2006). The quantity of sprints when considered in conjunction with the average sprint length for a back being 15.3m, (Cunniffe et al., 2009), would posit that emphasis in training must be given to developing acceleration over the first 15 metres. When training is undertaken for participation in any sports not only must the average game demands be considered but the worst-case scenario also must be considered, (Reardon et al*.,* 2017). Often, periods of play last longer than the average durations reported. Gabbett and Gahan, (2016) reported that often tries are scored as a result of repeated high intensity efforts and as such these are of value for research consideration. Gabbett et al*.,* (2014), found that the repeated high intensity efforts tend to occur in close proximity to each opposition try line.

Due to the longer recovery periods afforded players in the backs it is important that they have a well-developed aerobic system as this will make their recovery periods more efficient. A well-developed aerobic system aids in the recovery from high intensity intermittent exercise, (Tomlin & Wenger, 2001), like rugby union. This is due to a quicker replenishment of phosphocreatine essential for maximal intensity bouts of activity such as sprinting. Other factors are improved like rate of lactate clearing and a greater aerobic response to elevated post-exercise oxygen consumption (EPOC), Wilmore et al*.,* (2008). An efficient anaerobic system is also a key component of fitness for a rugby union player with McClean, (1992), measuring blood lactate concentrations at different time points during a first-class match with concentrations found to be between 5.8-9.8 mmol/L. This would suggest that rugby players are exercising anaerobically during match play, although in this study samples were taken during penalties and stoppages in play for injury so there may have been variance in the intensity and movement demands of the preceding passages of play. In this study, it was also observed that a contact situation such as a scrum, ruck or maul occurs on average every 33 seconds (s), so with high density work periods such as this a highly developed anaerobic system is essential. Reardon et al., (2017), stated that players may be involved in 0.28 – 0.89 collision events per minute, depending on playing position.

Anthropometric characteristics vary between positions on a rugby team. Front row forwards (props and hookers), tend to have the greatest body mass and tend towards mesomorphic or endomorphic somatotypes and have low levels of ectomorphy, whereas the inside backs tend to be shorter and lighter, (Quarrie et al., 1996). According to Quarrie et al., (2012), forwards also sustain more heavy contact situations than backs through scrums, rucks, mauls and lineouts. The mechanical strain placed on a front row forward during engagement of the scrum was measured at a peak of 16.5 ± 1.0 kilo Newtons (kN) of force. Due to the high levels of strain placed on rugby players in general and forwards in particular, it is important that the players are properly conditioned to sustain these forces. It was found by Crewther et al., (2009), that forwards have the greatest absolute power output of any players on a rugby team, as measured by box squat, bench throw and squat jump. However, when power was expressed relative to body mass i.e. relative power, then it was found that players from the backs tended to develop more power per kilogram (kg) of body mass.

The research gathered above demonstrates the dynamic nature of rugby. Due to the mix of power, speed and strength, rugby players need to be as dynamic as the game itself. To excel at the game, players need to have a high level of speed, strength and power. The aerobic, anaerobic and anaerobic-alactic systems of the body need to be very well developed to allow athletes to maintain the high-intensity required for the full duration of a match. Further to the high levels of fitness, there is a high level of musculoskeletal strength and power required due to the high-impact collision nature of the game.

Rugby players need to be well rounded multi-dimensional, athletes and their training needs to reflect this. With many different physical capacitates being trained and developed in rugby union, it is important that as the players are well round, multi-dimensional athletes a monitoring program needs to be well round and multi-modal. Due to the high metabolic demands of rugby union as evidenced by Duthie et al*.,* (2003), the high neuro muscular demands of the game as reported by Quarrie et al*.,* (2012), and Cunniffe et al*.,* (2009), it is important that a monitoring program that can account for all the stressors incurred in rugby union. Furthermore, due to the differences in positional demands and positional physical characteristics as observed by Quarrie & Hopkins, (2007), monitoring methods need to be individualised to accommodate all players and athletes.

Objective Measures of Training Load Response

Endocrine Response to Rugby Union

Testosterone

Hormones play a key role in regulating human muscle metabolism and anabolic hormones are of interest in sport science, (Cardinale and Stone, 2006). Testosterone (T) has received a lot of attention because of its well know effect on skeletal muscle growth, having a generally protein anabolic (synthesis) effect. Testosterone is an endogenous hormone which is the principal androgenic steroid produced by the testes, (Jones and Lopez, 2006), and is the end product of the hypothalamus-pituitary-gonadal (HPG) axis. Studies have shown a link between serum testosterone level and muscle function, (Urban et al*.,* 1995). Part of its effect on muscle may be mediated by insulin-like growth factor 1 (IGF1) which is a stimulator of cell growth and proliferation. It has also been shown to ameliorate the catabolic effect of glucocorticoids, (Mauras and Beaufrere, 1995).

Testosterone concentrations are highest in the morning and lowest in the evening. Testosterone levels for males less than 20 years of age have been observed to be 21.97 nmol/L with a range of 19.75 – 24.36 nmol/L in the morning and 16.03 nmol/L with a range of 13.90 – 18.37 nmol/L in the evenings, (Boyce et al*.,* 2004). However, there is no consensus among clinicians as to what testosterone concentrations are "normal", Feldman et al*.,* (2002). Studies have shown much lower concentrations of testosterone with Maso et al*.,* (2003), observing testosterone levels of 352 pmol/L (0.352 nmol/L) in international rugby union players in the morning and 308 pmol/L (0.308 nmol/L) in the evening. This variance in reported ranges between studies and the lack of consensus between clinicians and researchers can make comparisons between studies and populations difficult. In the context of training load monitoring establishing individual baseline concentrations and determining changes relative to this seems the intuitive way to monitor testosterone in athletic populations.

Serum testosterone samples are a valid and reliable method of determining testosterone concentrations, (Lane and Hackney, 2015), however, some subjects can be reticent about providing serum samples due to discomfort or anxiety, (James and Dabbs, 1990). Salivary samples can be used to determine testosterone levels as a non-invasive and less stressful alternative, (Wit et al, 2017). Wit et al (2017), in a study of 2049 subjects (696 males and 1352 females) found that there was a significant association between salivary and serum testosterone in both sexes, ($p = 0.01$ and $p = 0.001$ respectively). There has been shown to be a significant association between salivary testosterone and free and serum testosterone in men and women, ($p = 0.01$ and $p = 0.001$ respectively). Lane and Hackney (2015), demonstrated that there was a significant increase in both salivary and serum testosterone with moderate and high intensity exercise, ($p < 0.01$). There were strong positive correlations between both serum and salivary testosterone for moderate and high intensity exercise, ($r = 0.912$, $p < 0.001$ and $r = 0.898$, $p < 0.001$ respectively). In this study exercise intensity was defined as a percentage of VO_2Max. It has been shown that salivary testosterone response is reliable over long time courses, (James and Dabbs, 1990), but suggested that samples always be tested in duplicate to insure accuracy of measurements.

Males have been shown to have 10-20 times higher testosterone concentrations than females, (Davison et al*.,* 2005), with testosterone shown to be responsible for the greater muscle hypertrophy, and in part the strength differences between men and women. However, when strength is considered relative to lean body mass, women have been reported to be as strong as men in the lower limb, (Bosco et al*.,* 2002). Where there was a difference between the sexes was in the high-velocity portion of the force-velocity relationship with males demonstrating greater velocity and power than females, ($p < 0.001$). This may be due to the proposed effect that testosterone has on neuromuscular transmission, (Blanco et al*.,* 1997), modulating choline acetyltransferase (ChAT) and messenger ribonucleic acid (mRNA) levels in rats. Choline Acetyltransferase plays a key role in acetylcholine (ACh) synthesis which is a neurotransmitter, therefore it has been suggested that increased testosterone may not just affect skeletal muscle mass but also neuromuscular function. This would indicate that testosterone could play a role in muscle activation during rapid movements.

Cardinale and Stone, (2006), corroborated this showing a significant positive relationship between vertical jump performance and testosterone concentrations ($r=0.61$, $p < 0.001$). There is a correlation between testosterone and running speed with Crewther et al*.,* (2009), demonstrating a significant correlation between salivary testosterone measures (Sal-T) and 10 metre (m) ($r=-0.48$, $p < 0.05$) and 20m sprint times ($r = -0.56$, $p < 0.01$). The relationship between testosterone and performance as evidenced here suggests that monitoring this biomarker would be beneficial as it could be indicative of readiness to perform. Due to the importance of physical capacities such as strength and speed in rugby union and the role testosterone plays in these, a marker of individual athlete testosterone concentrations may give an indication of an athlete's capacity for physical performance in an upcoming training, match or competition.

Hough et al*., (2011),* examined the effect of different aerobic interventions on testosterone and cortisol response. They identified an increase in testosterone immediately post both continuous cycling to fatigue and high intensity interval training with all protocols performed on a cycle ergometer. Greater increases in salivary testosterone were observed in the high intensity intermittent exercise protocols than the continuous exercise protocol. This would be similar to the movement patterns in rugby union, with research establishing that rugby union consists of periods of high and low intensity intermittent activities, (Austin et al*.,* 2011). McLellan et al*.,* (2010), found that there was a slight increase in testosterone following rugby league match play when compared to pre-match but that testosterone was significantly lower than

24 hours' pre-match. The 24-hour pre-match testosterone concentration could have been anticipatory of the impending game. Changes in hormonal concentrations in anticipation of competition or matches have been well established, (Salvador et al., 2003). In a study on another collision sport (American Football) it was found that there was no change in testosterone immediately post-match play, (Kraemer et al.¸ 2009). Although American Football has the highest periodic intensities of all football codes, (Reilly and Gilbourne, 2003), the longer rest periods allow for full recovery between bouts of activity which would lead to a difference in testosterone response between rugby union and American Football. There is a much higher metabolic requirement in rugby than American football, (McLellan et al*.,* 2010). In contact sports, like rugby league and rugby union, however, the research into expected changes in testosterone has been equivocal.

Hayes et al*.,* (2015), in a meta-analysis of hormonal response to exercise have shown that there is a change in testosterone concentrations in the body in response to exercise. Different exercise protocols produced varying levels of response. It was found that acute aerobic and resistance training increased testosterone levels (however, with large differences in effect size depending on the study) but the effect of power-based exercise was less clear showing both increases and decreases in testosterone depending on the study protocol used. Testosterone follows a diurnal rhythm so when examining changes in levels this needs to be considered, (Wood and Stanton, 2012), with testosterone concentrations peaking in the morning and declining over the day increasing again at night during sleep, (Dabbs, 1990a). Testosterone can be affected by multiple other mechanisms including psychological, social, physiological and competitive events, (Gaviglio and Cook, 2014). Similar to monitoring an athlete's testosterone concentrations to ascertain their immediate capacity for physical performance, if an athlete's individual testosterone concentrations are determined and monitored then training can be manipulated and adapted to optimize testosterone concentrations. Cook et al*.,* (2014), determined that morning resistance training (lifting > 90% 1RM) maintained testosterone concentrations 6 hours later compared to a control group. The control group testosterone concentrations decreased as would be expected due to circadian rhythmicity. The resistance exercise modulated testosterone concentrations in the resistance training group led to greater counter movement jump and sprint performance later in the day and as such monitoring of testosterone concentrations as a marker of readiness to perform may be useful in professional sport.

Testosterone also has a psychological mechanism and plays a role in aggressive or competitive behaviour, (Terburg et al*.,* 2009). Testosterone is related to the behavioural activation systems (BAS) which is a model of behaviour described by Gray, (1987), that is related to high HPG activity and relates to aggressive and/or dominant behaviours, (Trainor and Nelson, 2007). In a study on psychological interventions on testosterone, Carré and Putnam (2010), found that watching footage of a previous victory produced a mean increase of 42-44% in testosterone from base levels (p = 0.02) in elite male hockey players. When players were shown a video of a match which they had lost there was only a mean increase of 6% when compared to base lines (p = 0.56).

It has been shown that an increase in testosterone after a successful aggressive encounter would lead to greater aggression in subsequent encounters showing the role of testosterone in modulating future behaviour, (Trainor et al*.,* 2004). In a study using video games with opportunities for aggressive behaviour, Carré and McCormick, (2008), found that aggressive behaviour was highly linked to increases in testosterone and resulted in an increased willingness to compete. In a study which examined match performance and pregame testosterone levels in professional rugby union players, Cook et al*.,* (2014), indicated that greater testosterone concentrations were associated with improved performance in a game. Performance was rated by a coach using a 1-5 scale of performance. As with physical performance, if testosterone is related to skill or game performance then it follows that a measure of an athlete's testosterone in the preceding days or hours may be indicative of their propensity for successful participation in a match or competition. If their testosterone concentrations are low relative to their baseline, then psychological or physiological interventions can be performed to increase testosterone in an athlete.

Testosterone has been shown to correlate to psychological measures of overtraining, (Maso et al*.,* 2003). It was observed in their study that there was a correlation between testosterone concentrations and overtraining score as determined by a psychocomportemental questionnaire. A correlation of (r = -0.6, p > 0.01) was observed between mean testosterone and overtraining score at all times of the day (0800, 1100, 1700). However, acute relationships between testosterone and psychological measures such as self-reported mood have been ambiguous with West et al*.,* (2014), observing no relationship between testosterone changes post a rugby union game and self-reported mood (p = 0.232). There are limited studies on the effects of testosterone and psychometric measures of training load, (Maso et al*.,* 2003). There is a need for the determination of the relationship between testosterone and psychological measures of over training such as perception of wellness measures.

From the current research into testosterone in relation to sport and exercise, it is clear the key role that it plays. Whether it is the role it plays in increasing muscle mass, (Davison et al*.,* 2005), or in increasing neural conduction through modulation of choline acetyl transferase and thus increased synthesis of the neurotransmitter acetyl choline, (Blanco et al*.,* 1997), the role of testosterone in sport performance is evident. It also has a role on competitiveness and aggression, (Carré and McCormick, 2008), which can be determinants of success in sporting events. Testosterone concentrations are affected by the mode, intensity and volume of exercise undertaken, (Hayes et al*.,* 2015), so monitoring of the hormone during training and competition would be of great benefit to ensure that athletes hormonal environment is conducive to successful participation in their given sport or event, (Handziski et al*.,* 2006). The determination of testosterone's relationship with other measures of training load monitoring and training response will allow for indirect indicators of hormonal environments. Due to the time consuming and expensive nature of saliva analysis this would allow for more practical measures that may be used which have a biological basis for other training load measures.

Cortisol

Endocrine response to varying types of stress and exercise have been studied and another important hormone to consider is cortisol (C). Cortisol is the primary glucocorticoid in humans and plays a major role in metabolism and immune function, (McGuigan et al*.,* 2004). Cortisol is considered an indicator of hypothalamic-pituitary-adrenal (HPA) axis activity which responds to a wide variety of stressors such as competitive situations, (Gaab et al*.,* 2005). "Stress is the generalized, nonspecific response of the body to any factor that overwhelms or threatens to overwhelm, the body's compensatory abilities to maintain homeostasis.", (Sherwood, 2005).

Cortisol is the end product of the HPA axis similar to testosterone being the end product of the HPG axis. Cortisol has several key functions in the body including; stimulation of gluconeogenesis, increased mobilisation of free fatty acids (FFAs) making them more available as an energy source, decreased glucose utilisation to ensure adequate supply for the brain and protein catabolism to allow use of amino acids for repair, enzyme synthesis and energy production, (Wilmore et al*.,* 2008). Increases in cortisol levels have shown an increase in protein degradation and inhibition of protein synthesis which suggests that long term elevated cortisol could lead to muscle wasting and proteolysis, (Kraemer et al*.,* 2001). As stated earlier in this section due to the anabolic nature of testosterone and the catabolic nature of cortisol the ratio of the two of these hormones will give an indication of the body's anabolic/catabolic balance, (Shanks and Macdonald, 2014).

Much like Testosterone, there is no consensus on normal ranges for cortisol, (Clow et al*.,* 2004). Studies have reported normal values of 4.7 nmol/L, (Brooke-Wavell et al*.,* 2002), to 15.0 nmol/l, (Wust et al*.,* 2000). This can make comparison between studies difficult. It has also been observed that cortisol concentrations can fluctuate as much as 156% during the course of a day with diurnal rhythmic variations. Cortisol concentrations are generally highest 30 minutes post waking. Exercise will also increase levels of cortisol in athletes, (Hayes et al*.,* 2015), with distinct exercise protocols showing varying cortisol responses. Hough et al*.,* (2011), showed that aerobic exercise interventions show a significant increase in cortisol. Athletes performing exercise to volitional fatigue or bouts of intervals of cycling at different percentages of max power showed a significant increase ($p < 0.01$) in salivary cortisol pre-exercise to immediately post exercise. Peak salivary cortisol levels occurred approximately 30 minutes' post exercise. When comparing the aerobic protocol to a resistance training protocol (8 sets of 10 repetitions at 10 rep max squatting) there was significantly greater increase ($p < 0.01$) in cortisol immediately post exercise when compared to pre-exercise values.

In a study on biochemical and endocrine responses to collisions in rugby union, it was observed that there was a significant increase in cortisol from 24 hours' pre-match to

30 minutes' post-match and 24 hours' post-match, ($p < 0.001$), (McLellan et al., 2011). 24-hour pre-match cortisol levels were 10.1 ± 1.3 nmol/L compared to 21.9 ± 4.4 nmol/L and 15.3 ± 3.5 nmol/L 30 minutes and 24 hours' post-game respectively. However, there was no correlation found between peak cortisol concentration (21.9 ± 4.4 nmol/L across all positional groups) and number of tackles (14.9 ± 10.5 across all positional groups).

Athletes are at an increased risk of injury and illness, (Penna et al*.,* 2003). This may be due to prolonged presence of post exercise catabolic hormones such as cortisol; which may impair muscle growth and repair due to inhibition of anabolic factors such as growth hormone and insulin-like growth factor. Due to the immunosuppressive effects of cortisol, sustained training-induced cortisol elevation may result in viral infection, athletic injury and training maladaptation. While cortisol is an important mediator of metabolic function in the human body, being involved in gluconeogenesis and metabolism acceleration, it must be monitored due to its catabolic effect on musculoskeletal protein. Obviously, a loss of muscle would be detrimental to athletic performance and counterproductive to the hypertrophic intention of many strength and conditioning programs.

As there is ambiguity in the research as to normal concentrations for cortisol it may be difficult to make recommendations based on single or limited cortisol sampling in athletic populations, as such it would be valuable to establish base line cortisol levels for individual athletes. As such deviations in endocrine response in relation to training load may be indicative of the athlete's hormonal response to training and if they are at risk of maladaptation to training. As time lost to illness can be as disruptive to a season as time lost to injury, the immunosuppressive effect of cortisol means that monitoring of this hormone could be beneficial in high levels sports.

Due to the high cost of cortisol analysis and the need for specialist equipment and skills, it can be restrictive for some teams and athletes to track cortisol response frequently or over a season. As such, if other more practical or cost-effective methods may be correlated to and therefore considered indicative of endocrine response to training load response then these could be used confidently by sport science practitioners. To that end this study aims to determine cortisol's relationship with other training load measures.

Testosterone-Cortisol Ratio

As testosterone and cortisol are important hormones to consider for athletic performance, the ratio of the two has been examined in relation to performance and training. The testosterone to cortisol (T:C) ratio is generally considered to be viewed as an indicator of the anabolic to catabolic hormonal balance within the body, (Budget, 1998). It has been suggested as a useful tool in the early detection of overtraining, (Banfi, 1998). Low free testosterone in the blood and a reduction of T:C by greater than 30% may be indicative of overtraining, (Kraemer et al., 1998). The reason for the change in T:C ratio may vary; it could be due to an increase or decrease in testosterone and accompanied by no change (or a less pronounced change) in cortisol or vice versa, (Handziski et al*.,* 2006). Repeated heavy exercise can cause a chronic disturbance in the ratio between testosterone and cortisol but even a single bout of exercise may induce transient changes in the anabolic-catabolic balance, depending on the intensity and length of the exercise bout, (Maso et al*.,* 2003). The studies tend towards focusing on individual bouts of exercise and as such examination of the hormonal ratio over a longer time frame may be indicative of its response to a full athlete performance program.

Few studies have examined the relationship between psychological measures of overtraining and testosterone or cortisol concentrations, (Maso et al*.,* 2013). The study by Maso et al*.,* aimed to determine the correlation between measures of overtraining (as measured by way of 54 psychocomportemental questions) and overtraining. It was found that there was a negative correlation between testosterone and overtraining scores (r = -0.43 - -0.6, $p < 0.05$), however, no correlation existed between cortisol and overtraining score. There was a negative correlation between overtraining score and T:C ratio (-0.43, $p < 0.05$). This study found that testosterone and the testosterone to cortisol ratio was more useful to follow as cortisol did not seem to correlate with overtraining. As with testosterone and cortisol individually, monitoring of this hormonal ratio can be restricted by facilities or resources so if it can be correlated to less restrictive training load methods such as psychometric questionnaires this would be invaluable.

Due to the large physical and metabolic demands of rugby union, disruption of testosterone and cortisol may occur post-match or training, (Elloumi et al., 2003). It was found by McLellan et al., (2011), that a ~25% reduction in peak rate of force development and a ~20% reduction in peak power 24 hours post-match which was associated with a ~51% increase in cortisol, demonstrating an impairment of neuromuscular performance as a result of the increased cortisol. West et al., (2014), found that testosterone to cortisol ratio was altered at 12 hours and 36 hours post a rugby union game but was returned to baseline levels by 60 hours post-game. This change in T:C ratio at 12 and 36 hours was due to both an increase in cortisol from baseline levels (0.40 ± 0.09 µg/dL, 0.60 ± 0.20 µg/dL and 0.60 ± 0.20 µg/dL respectively) and a decrease in testosterone (214 ± 84 pg/mL, 151 ± 56 pg/mL and 173 ± 56 pg/mL respectively) from baselines levels. Both testosterone and cortisol returned to close to baseline levels by 60 hours post-game. In contrast to the findings by McLellan et al., (2011), the changes in testosterone, cortisol and T:C ratio did not relate to any change in peak power output (PPO) or jump height as measured using a force plate during a countermovement jump ($p > 0.05$). It has been suggested by Crewther et al., (2011) that increases in cortisol concentrations having an inhibitory effect on testosterone synthesis may explain the opposing time course changes in testosterone and cortisol.

Testosterone to cortisol ratio has also been found to be an indicator of proneness to social aggression, (Terburg et al., 2009). In a review of the evidence for a biological basis for social aggression and aggressive behaviour, it was found that that elevated levels of testosterone and low levels of cortisol have been associated with social aggression. A high testosterone: cortisol ratio may result in more confrontational behaviour, more motivational tendencies to confront threats, less reversal of aggressive tendencies and less experience of fear. While these traits may be undesirable in social situations if they lead to aggressive behaviour, their benefit in sport, particularly in a physically combative sport like rugby union, are obvious. The ratio between the two may be indicative of readiness to perform physically and to compete.

Both testosterone and cortisol exhibit circadian rhythmicity, (Cook et al*.,* 2013), with both displaying an early morning peak before declining across the waking day. Due to the influence that these hormones have on athletic performance, it is important to understand the diurnal variation of these hormones. Cortisol peaks in the morning to accelerate metabolism, stimulate gluconeogenesis and proteolysis while the morning increase in testosterone may be to counteract the skeletal protein degradation cause by cortisol, (Hayes et al*.,* 2010). Cook et al*.,* (2013), found in their study of performance at different times during the day in relation to hormonal rhythms that increased afternoon testosterone did lead to greater performance, in this case measured via sprint times and jump heights. However, they were unclear if this relationship was causal or reflective of readiness to train. It may be due to other confounding biological processes such as an increase in core and muscle temperature later in the day.

Testosterone to cortisol ratio is a biological marker that it is intuitive to monitor for players and participants involved in high level sport. Due to the indicative nature of this hormonal ratio to the anabolic or catabolic state of an athlete, it can be used to determine how an individual may respond to a given training stimulus, load or program. As both hormones can be manipulated through different interventions, knowledge of an athlete's internal environment may give the opportunity for sport scientists and strength and conditioning professionals to perform interventions that may produce a more favourable hormonal environment for high performance.

As with testosterone and cortisol separately, the establishment of individual baselines for this hormonal ratio is essential and deviations below or above baseline may be indicative of likelihood for injury or illness or indeed readiness to perform. As previously stated, the analysis of hormonal response can be restrictive due to limited resources, facilities or laboratory skill so if this hormonal marker can be correlated to other measures of training load response it would be invaluable to teams and athletes.

Global Positioning Systems

In recent years, the use of global positioning systems (GPS) in team sports has increased rapidly which allows access to in-depth, objective measures of performance such as total distance and distances covered in velocity bands, (Colby et al*.,* 2014). GPS data has been used to both determine the workload of players and its relationship with injury, (Gabbett and Ulah, 2012), as well as locomotor performance metrics that may influence match outcome, (Bauer et al*.,* 2015). As a technology which has only recently been used in a sport and athletic performance context there has been a lot of research into its validity and reliability, (Boyd et al*.,* 2011. Gabbett, 2013. Scott et al*.,* 2015).

Scott et al*.,* (2015), in a review of current literature on both the validity and reliability of GPS units for quantifying movement, patterns have observed variances between units with different sampling rates. It was observed that units sampling at 1 Hz were able to accurately report distances at lower velocities of movement (< $5ms^{-1}$) with a standard error of estimate (SEE) of between 0.5% and 2.1%, however, at higher intensities the SEE was 10.4% to 12.7% indicating poor validity at these velocities. It was found in their review that although the validity of 1 Hz units for reporting distances covered at higher velocities may have had higher than acceptable standard errors of estimate (> 10%) the report of total distances covered showed good validity (SEE = 3.6%). Similarly, reliability of 1 Hz units was affected by the velocity of movement with lower velocity movements having a coefficient of variance (CV) of 5% whereas high intensity running had a CV of 11.2% to 32.4%. Jennings et al*.,* (2010), showed that both 1 Hz and 5 Hz GPS units reliability was affected by the distance over which the measurement was taken with a CV of 30.8% and 23.3% respectively when measuring walking pace over 10m. The CV in the same study was considerably improved over 40m with 1 Hz units having a CV of 7% and 5 Hz units having a CV of 6.6% at walking pace. The velocity of the movement affected the reliability also, with the CV over 10m at sprinting pace being 77.2% for 1 Hz units and 39.5% for 5 Hz units. As with the slower velocities this improved to 11.5% and 9.2% respectively over the longer distance (40m). This shows that reliability decreases as velocity increases and distance decreases and reliability increases as velocity decreases and distance increases.

In relation to velocity bands an issue is the definitions used in varying studies for different velocities (i.e. sprinting, walking, jogging etc.), as there are no consistent definitions of for velocity bands at present, it can make comparing studies and different sports difficult, (Dwyer and Gabbett, 2012).

Advancements in GPS technology in recent years have seen the development of units with higher sampling rates. Castellano et al., (2011), in a study on the reliability and validity of 10 Hz GPS units observed that there was a CV% of 1.3% and 0.7% for running speeds over 15m and 30m respectively. The CV over 15m of 1.3% for the 10 Hz unit when compared to 39.5% for the 5 Hz units over the similar distance of 10m examined by Jennings et al*.,* (2010), demonstrates that increase in sampling rate improves the reliability of the GPS units. However, the study by Castellano et al*.,* only examined reliability and validity in straight line running and may be confounded by changes of direction. The reliability and validity of 10 Hz and 15 Hz GPS units was also examined by Johnston et al*.,* (2014), determining that the units with the higher sampling rates measured movement demands with greater validity and reliability than the 1 Hz and 5

Hz GPS units. It was observed that 10 Hz units were valid and reliable for measuring total distance (*r* = 0.51, TEM% = 1.3), peak velocity (*r* = 0.97, TEM% = 1.6), low speed and high speed running distances (*r* = 0.97 and 1.7 respectively, TEM% = 1.7 and 4.8 respectively). The findings of Johnston et al*.,* determined that 10 Hz units were more reliable and valid than 15 Hz units for measures such as total distance and peak speed (*r* = -0.2 and -0.14 respectively, TEM% = 1.9 and 8.1 respectively). For the higher 15 Hz units the distance at low speed running metres and high speed running metres were acceptable, (*r* = 0.98 and 0.94 respectively, %TEM = 2.0 and 7.6 respectively). It is important when using GPS data to quantify training load that it is reliable and valid and the present research to date indicated that GPS units sampling at 10 Hz provide a reliable and valid measure of distance and velocity related metrics, however, with the limited amount of studies on 10 Hz GPS units there is call for further validation and determination of reliability.

The accuracy with which GPS units report collisions must be considered, as collisions are an integral part of rugby union and contribute to the external training load of players. Cunniffe et al*.,* (2009), reported that backs were involved in 798 impacts in a game while forwards were involved in 1,274 as measured using GPS. When this is compared to 24 for backs and 89 for forwards as was reported by Roberts et al*.,* (2006), using TMA this figure seems excessive. As impacts or collisions are generally measured using change in velocity per unit of time, the same as accelerations and decelerations, this could again indicate poor reliability in GPS units to report these values accurately. Gabbett, (2013), also questioned the ability of GPS units and micro sensor technology to quantify contact loads in collision sports such as Rugby Union, with further research needed to validate these measures. In a review of wearable microsensor technology, Chambers et al*.,* (2015), suggested that they were unable to distinguish between tackles and other events such as rucks, mauls and scrums in rugby union. This could be due to the use of algorithms that were originally developed for use in Australian Rules football where the nature of collision or contact events would be different, which could result in misidentification of events and reporting an incorrect volume of collisions. There is need to further study the reliability and validity of GPS technology to accurately record and report the quantity and intensity of collisions as they are an integral part of rugby union and as such are a large part of a players external training load.

There is a lack of consensus on the definition of velocity bands across different research and sports which makes it nearly impossible to compare findings among studies, (Dwyer and Gabbett, 2012). In their study, which attempted to give a uniform definition of speed bands, Dwyer and Gabbett examined the speed bands in other studies and found that the range in definition of bands subjectively described as “running” could range from 2.8 ms^{-1}, (Bangsbo et al*.,* 1991) to 4.0 ms^{-1}, (Doğramaci and Watsford, 2006). It is worth noting that these speed bands were defined in studies using Time Motion Analysis (TMA) which has been shown to have good inter-rater and intra-rater reliability, however, no data exists to compare it to a valid criterion measure to confirm accuracy, (Reardon et al*.,* 2015). In this paper, the authors noted that not only is there an issue with a consensus in the definition of speed zones but also that there is an issue with using universal speed bands and applying this to all players. It was found that when high speed running metres (HSRM) were defined at the arbitrary absolute value of 5ms^{-1}, as defined by the GPS unit supplier, when compared to an individual threshold of 60% of maximum velocity there was an over estimation of HSRM for backs and an underestimation for forwards. Forwards HRSM when defined using the absolute value were 269m ± 172.02m which was significantly lower ($p < 0.001$) than the individually defined HSRM of 354.72 ± 99.22. Backs HSRM were 697.79m ± 198.11m when defined by the absolute threshold which was significantly higher ($p < 0.001$) than the individually defined HSRM of 570.02m ± 171.14m.

This study used an individual threshold of 60% of a player's individual maximum velocity. 60% of maximum velocity as a threshold for high speed running metres was determined by dividing mean group maximum velocity (8.3 ms^{-1}) by the common arbitrary threshold of 5 ms^{-1}, so there is still an element of arbitrariness in this figure. Buchheit et al*.,* (2010), in a study on repeated sprint sequences during youth soccer matches used a similar threshold for sprints of 61% of the individual peak running velocity. 61% was used as the threshold here as it was stated by Duthie et al*.,* (2006), that 61% is the highest likely speed to be reached in 1s after a standing start sprint. Duthie et al*.,* (2003), reported that in rugby union; outside backs have a maximum running velocity (Vmax) 37% higher than forwards. This would indicate that the use of arbitrarily defined running speeds could overestimate the running loads of some players and underestimate the running loads of others. The use of universal arbitrary thresholds therefore, does not account for the sprinting "capacity" of individual players; faster players may run at a lower percentage of their maximum velocity and slower players may run at a higher percentage of their maximum velocity, (Gabbett, 2015).

There have been physiologically based thresholds for high speed running metres proposed in previous research. In a study on high speed running metres in female rugby sevens players, Clarke et al*.,* (2015), individual high speed running thresholds were set at the second ventilatory threshold. Second ventilatory threshold corresponds to the point where carbon dioxide production exceeds oxygen consumption during exercise. They found that when using this marker as a threshold that high speed running metres could be overestimated by up to 14% when compared to the arbitrary threshold of 5 ms^{-1} for some players. This is the only study that was found that examined GPS measured high speed running distance using a physiological marker as basis for individual thresholds. The second ventilatory threshold has been used as a measure of high speed running distance in a study using Time Motion Analysis, (Abt and Lovell, 2009). They found that arbitrary thresholds of high speed running distance, in this case 5.5 ms^{-1}, overestimated high speed running distances as much 24%. The time spent exercising above second ventilatory threshold may be indicative of metabolic stress from a game and as such could inform recovery protocols or future conditioning protocols. To date there is no research on the validation of high speed running metres definitions against another measure of training load such as sRPE or another internal measure of training load response. While a physiological basis for individual thresholds is intuitive to inform recovery and training strategies been used in a given sport there is need for further studies to determine which physiological markers to use.

There could be a biomechanical perspective through which velocity thresholds could be examined. In a study by Schache et al., (2011), it was found that when running at 3.5 ms^{-1}, the ratio of peak hip to knee extensor moments was 0.29:1.0, whereas when running speeds increase to 5.02 ms^{-1} the ratio increases to 0.4:1.0. At a velocity of 8.95 ms^{-1} the peak hip to knee extensor moment ratio increases to 1.18:1.0, which shows as running velocities increase there is a greater involvement of the hip in extension moving towards hip dominance. The amount of time spent at or above different velocities would indicate the involvement of different joints and muscle groups to the movement and, as such, may inform strength and conditioning practices such as exercises used. While this is not examined in this study it is worth noting the different perspectives under which velocity thresholds may be considered.

It is important to understand the running demands of different sports and different playing positions for the application of sport and position specific conditioning and recovery protocols. Therefore, it is important that the definition of speed bands are universal so that comparison of sports and studies may be facilitated but it is also important that the speed bands are individualised to allow for inter sport and inter speed positional differences. A physiological basis for individual speed bands seems intuitive and has been suggested in previous research, (Clarke et al., 2015), however, there needs to be further research into the use and definition of these thresholds. GPS technology is a valuable tool in furthering the understanding of movement demands of sport participation and performance. However, as it is a relatively new technology in the area of sport and exercise there is still a need for further investigation into its reliability and validity for quantifying different sport related activities. There is also a need for a general consensus on the definition of velocity bands for inter-study and inter-sport comparisons of the demands of sports. Furthermore, the use of player and position individualized speed bands rather than arbitrarily defined speed bands is essential to get a true reflection of the physiological demands imposed on them during training and competition to better tailor conditioning and recovery strategies to the individual.

Ankle Dorsiflexion

Acute ankle injuries are the most prevalent injury in sporting and athletic populations according to Doherty et al. (2014). Reduced Dorsiflexion is a clinical consideration when managing and rehabilitating lower extremity injuries, (Youdas et al., 2009). Decreases in Dorsiflexion are often the result of calf tightness, the calves being the muscle group consisting of gastrocnemius, soleus and plantaris muscles, (You et al., 2009), which has been identified as a risk factor for sustaining lower limb injuries, (Hadzic et al., 2009). In a study on the effect of ankle dorsiflexion range on injury risk in army recruits, Pope et al., (1998), found that there was a five-fold increase in risk of ankle sprain (p = 0.006) in subjects with a decreased range of dorsiflexion, less than 34°. There was no evidence of a significant relationship between decreased ankle dorsiflexion and risk of stress fractures, (p = 0.61). Use of consistent monitoring of an athlete's ankle range of motion should be used to determine throughout a season, in order to avoid ankle sprains and time loss injuries. Determining if athletes are below a certain range of motion for ankle dorsiflexion through an easy and repeatable test like the knee to wall test should be incorporated into an athlete monitoring program.

The weight bearing lunge test (WBLT) or knee to wall (KTW) test is a well-used test to assess range of ankle dorsiflexion, (Bennell et al*.,* 1998; Vicenzino et al*.,* 2006; Sman et al*.,* 2014.). It has been found to be a functional and reliable method to assess dorsiflexion by measuring the "maximal advancement of the tibia over the rearfoot in a weight bearing position". Bennell et al*.,* found there to be good inter and intra rater reliability. The intra-rater intraclass correlation (ICC) ranged between 0.97 to 0.98 and the Inter-rater ICC ranged between 0.97 and 0.99. Vicenzino et al*.,* found that subjects with asymmetries of 1-2 cms between left and right sides are assumed to have clinically relevant impairments. However, Hoch & McKeon (2011), found that there can be as much as a 0.1 cm ± 1.5 cm asymmetry between limbs in healthy adults. Their findings supported the recommendations of both Vicenzino et al*.,* and Reid et al*.,* (2007), which suggests that an asymmetry of 2 cm or greater is a clinically relevant impairment. Establishment of individual athlete base line measurements and monitoring of bilateral variances may be of value as part of a holistic monitoring program. Changes and asymmetries between ankles may be indicative of a maladaptation to training, a likely hood to underperform and a likelihood to get injured.

Sman et al*.,* (2014), have questioned the relationship of ankle dorsiflexion and injury prediction. In their study of 202 male rugby union and Australian football players it was observed that the weight bearing lunge test result had no injury predictive ability. They found that ankle dorsiflexion or muscle strength had no observable effect on ankle syndesmosis injury and in fact that only vertical jump performance and star excursion balance test were predictive of injury with higher vertical jump height relating to greater risk of injury. This contrasts with the previously examined research by Bennell et al*.,* (1998), and Youdas et al*.,* (2009), who contended that reduced ankle dorsiflexion is important to consider for injury prevention and injury management in all populations. It has been suggested that ankle dorsiflexion may be affected by body mass, (Huerta et al., 2008), due to changes in plantar fashion thickness relative to mass but this has not been widely studied and not in relation to injury or athletic performance.

Ankle dorsiflexion is a widely used musculoskeletal review and due to its simplicity of administration, non-invasive nature and repeatability it is worth considering. Although it’s role in injury prediction or prevention is equivocal in some research, further studies will need to be carried out to determine its efficacy. As Sman et al*.,* (2014), contend that vertical jump performance is a better predictor of injury than ankle dorsiflexion, an examination and comparison of the two measures in an athlete population would be valuable. This study will aim to determine the relationship between ankle dorsiflexion and other musculoskeletal measures such as hip adductor strength, neuromuscular performance, perceptions of wellness, training load and hormonal response. If ankle dorsiflexion can be related to measures of wellness it may indicate that reduction or improvement in perceptions of wellness may be related to changes of range of motion or stiffness in joints and limbs. If it relates to neuromuscular performance, then it may be indicative of likelihood to perform or capacity for performance.

Hip Adductor Strength

Chronic groin pain is common presentation in sports medicine practice, (Falvey et al*.,* 2009), and is reported to be the fourth most common injury sustained during rugby union training, (Kemp et al*.,* 2012). However, it is behind only fracture and joint reconstruction in terms of lost time from injury, (Brooks et al*.,* 2005). Falvey et al*.,* state that this is because kicking and twisting movements while running place a strain on fascial and musculoskeletal structures that may result in damage and cause pain local to the groin area. As well as kicking and twisting movements it has been linked to rapid acceleration and deceleration and sudden changes in direction, (Whittaker et al*.,* 2015). In order to avoid preventable groin injuries in field-sport athletes, it is important to identify modifiable risk factors, (Roe et al*.,* 2016). Whittaker et al*.,* in a systematic review of research on groin injury found that previous groin injury, higher-level of play, reduced hip adductor strength and lower levels of sport-specific training are associated with an increased risk of groin injury. Some of the risk factors involved in groin injury cannot be modified such as previous groin injury but one that is monitorable and modifiable is hip adductor strength.

The hip adductor squeeze test has been shown to be a valid and reliable measure of hip adductor strength, (Malliara *et,* 2009). The test involves placing a measurement device such as a sphygmomanometer between an individual's thighs and getting them to forcibly adduct (squeeze) their legs together to compress the device. Delahunt et al., (2011), suggested that a hip angle of 45 degrees of flexion is the best angle to elicit optimum adductor muscle activity and maximum pressure values. Mean pressure values in 18 male Gaelic footballers at 45 degrees of hip flexion were 236.76 ± 47.29 mmHg compared to 202.50 ± 57.28 at 0 degrees of hip flexion and 186.11 ± 44.01 at 90 degrees of hip flexion. This would suggest that for assessment of hip adductor strength using a groin squeeze method at a hip joint angle of 45 degrees is the optimum. In an investigation of adductor squeeze normative values for junior rugby players, Coughlan et al., (2014), found that elite junior rugby union players had a mean groin squeeze of 228.9 ± 37.92 mmHg at 45 degrees of hip flexion. There was no significant difference between position units (p = 0.84) with backs having a mean adductor squeeze value of 228.29 ± 36.53 mmHg and forwards having a mean value of 228.28 ± 39.25 mmHg. Players in the study were asymptomatic for groin pain or injury and as such considered healthy and injury free. Khayambashi et al., (2015), found that strength in hip abduction and external rotation were also good predictors of hip injury.

It was found that reduced hip external rotation strength increased risk of non-contact anterior cruciate ligament (ACL) injuries ([OR] = 1.23 [95% CI, 1.08 – 1.39], p = 0.001) as did decreased hip abduction strength ([OR] = 1.23 [95% CI, 1.05 – 1.20], p = 0.001).

Crow et al*.,* (2010), found that there was a decrease in hip adductor strength 2 weeks (1.99 ± 4.28%) and 1 week (5.83 ± 5.16%) preceding onset of groin injury. The week of injury there was a decrease in hip adductor strength from baseline of 11.75 ± 2.50%. The effect size for each of these differences were *d* = 0.26 (95% CI = -0.48 – 1.0) two weeks prior, *d* = 0.55 (95% CI = -0.19 – 1.31) one week prior and *d* = 0.98 (95% CI = 0.20 – 1.77) on the week of onset of pain or injury. This study supports the use of measuring hip adductor strength to determine if there is a risk of injury so that prophylactic measures can be taken to minimize avoidable time loss injuries in an athletic population.

In a study on the reliability and association with groin pain of measures of hip flexibility and strength, Malliaras et al*.,* (2009), found that the adductor squeeze test had good test-retest and interrater reliability, (*r* = 0.81-0.94 and *r* = .80 – 0.83 respectively) when comparing the groin squeeze at 0°, 30° and 45° of hip flexion. It was found that there was slightly greater test-retest and interrater reliability at 45° hip flexion than at 0° and 30°. It also found that there was lower adductor strength in those experiencing groin pain than in those who were asymptomatic. Subjects with groin pain had values of 172.3 ± 28.2 mmHg at 0° of hip flexion compared to 210.8 ± 39.3 mmHg in asymptomatic subjects at the same angle of hip flexion. Of all the measures of hip mobility and strength that were used (bent knee fall out test, internal hip rotation, external hip rotation and adductor squeeze test) the adductor squeeze test was the only one that showed a significant difference between those with groin pain and those without. Although, the reduction in the groin squeeze values may be due to either muscle weakness or pain inhibition.

Hip adduction is an effective, non-invasive and easily administered musculoskeletal review tool to use, as changes in the value may be indicative of potential for groin injury. Due to the length of time that may be potentially lost to groin injury, and the effect this could have on a team or players season, it is a simple and effective tool to use in a holistic monitoring program for athletes.

Neuromuscular Performance

There is a high requirement for neuromuscular performance in rugby union, (Crewther et al., 2009), with activities such as running, jumping, tackling and scrummaging that require high force-generation capabilities integral. The distinct positions involved in rugby union require different neuromuscular abilities, for example, halfbacks requiring high speed to accelerate away from players and into space compared to maximum strength required by a front row forward to gain and retain ball possession. Crewther et al., (2011), found that when comparing relative neuromuscular performance between backs and forwards in rugby union that there was no difference when using allometric scaling to normalize for body mass. There were correlations found between body mass, body height and performance when ratio scaling was used. The performance tests used in this study were sprint times over 10 and 20m, countermovement jump (CMJ) height, squat jump (SJ) height and horizontal jump (HRJ) distance. Strength tests were also performed which were 2-4 repetition maximum (RM) tests for bench press, chin up and back squat.

Countermovement Jump (CMJ) is a common test of neuromuscular performance and explosive power, (Markovic et al*.,* 2004). Measuring CMJ using a contact mat and a digital timer is a reliable and valid measure of explosive power in the lower limb of physically active men. Markovic et al*.,* suggested monitoring of countermovement jump to measure training response and adaptation. Gathercole et al*.,* (2015), found that the countermovement jump is a useful tool in monitoring fatigue in elite sport. In their study participants baseline countermovement jump was measured, with variables including jump height (m) recorded. Subjects were then asked to perform a fatiguing protocol (YoYo Intermittent Recovery Test2 and YoYo Intermittent Endurance Test2). Afterwards their countermovement jump performance was again recorded. It was found immediately after exercise that CMJ height decreased from 0.44 ± 0.11 m to 0.40 ± 0.09 m (ES -0.34). This started to return to baseline 24 hours post (0.43 ± 0.01 m (ES -0.08)) and was above baseline 72 hours post exercise (0.46 ± 0.08 m (ES 0.18)). However, it must be noted that compensatory mechanisms in motor pattern may have allowed for the recovery of jump height while there was still residual fatigue from the exercise protocol. Maximum rate of force development (mRFD)was 14,926 ± 9118 Ns at baseline but was reduced to 12,190 ± 6008 Ns (ES -0.30) and remained decreased 24 hours and 72 hours post exercise (12,958 ± 7643 Ns (ES -0.22) and 12,666 ± 5630 Ns (ES -0.25) respectively). Changes in biomechanics may have allowed for the maintenance or quick recovery of the jump height but the ability to generate the same level of force remained impaired. Understanding the timeframe over which neuromuscular performance is affected will allow for proper prescription of training and periodisation within a microcycle.

Twist et al*.,* (2012), in a study of post-match fatigue in rugby league players found that countermovement jump performance was decreased for all players post-match ($p = 0.002$) with no interaction between time played and playing position. Forwards flight times decreased from a pre-match value of 0.61 ± 0.04 s to a nadir of 0.59 ± 0.06 s (ES -1.3) 24 hours post-match. Backs flight times were recorded at a pre-match value of 0.66 ± 0.04 s to a low of 0.64 ± 0.03 (ES -0.8) 48 hours post-game. Interestingly there was found to be a negative correlation between number of contacts in a game ($r = -0.48$, 95% CI -0.75 to -0.09, $p < 0.05$) and countermovement jump flight time. There was a positional difference in this value with backs having a negative correlation of ($r = -0.25$, 95% CI -0.76 50 0.45, $p > 0.05$) whereas forwards had a negative correlation of ($r = -0.55$, 95% CI -0.85 to -0.01, $p < 0.05$). This may be due to the total greater number of contact events engaged in in a match by forwards (25.2 ± 8.0 for the backs compared to 38.2 ± 18.7 for the forwards). The correlation between flight time reduction and number of contacts may be due to eccentric muscle damage from accelerations and declarations associated with tackling. The increased loading of the lower limb involved with contact may also affect flight time. For backs, there was a longer decrease in flight time as measured by CMJ compared to the forwards which is consistent with low frequency fatigue. This type of fatigue is caused by active lengthening of skeletal muscle during high intensity activity which invokes muscle damage and will impair performance. Understanding positional differences in neuromuscular performance and how it is affected by training and competition will allow for a greater understanding of the training strain of different positional groups and greater specificity in training.

This study aims to determine if there is a relationship between the different training load measures that may be employed, such as perceptions of wellness measures or musculoskeletal reviews and neuromuscular performance. As it has been shown in previous research that there may be decrements in neuromuscular performance for up to 72 hours understanding how this may be affected by and interact with different facets of training load response would be beneficial to sport science and strength and conditioning practitioners. If there are continuous or chronic decreases in neuromuscular performance throughout a season, then this may be seen as a maladaptation to training and that athletes training programs need to be reviewed. If there are increases in neuromuscular performance and perceptions of wellness are high or stable concurrent with appropriate training loads, then this will be indicative of a successful training program. As neuromuscular components such as strength and speed are usually physiological determinants of success then maintenance and improvement of these is essential. An understanding of the relationship of the different measures of training load response and how they may affect neuromuscular performance may allow for more effective periodisation and programming around periods of decreased neuromuscular performance and may allow for strategies to ameliorate performance decrements at periods where performance may be affected.

Subjective Measures of Training Load Response

Session Rate of Perceived Exertion

A session rating of perceived exertion (sRPE) is based on the understanding that an athlete can inherently monitor the physiological stress exerted on their bodies during exercise, (Borresen and Lambert, 2009). SRPE was proposed as a simple and non-invasive means whereby internal response to exercise can be monitored subjectively, (Lovell et al*.,* 2013). Borg stated in 1982 that, “perceived exertion is the single best indicator of the degree of physical strain”. This is due to the integration of various sensory information from the main signals elicited from the peripheral working muscles and joints to the cardio-respiratory system and the central nervous system.

Rating of perceived exertion has been used for many years with different scales been utilised. Foster, (1998), developed a 10-point scale to quantify training load whereby the duration of the session (in minutes) is multiplied by the self-reported level of exertion which gives training load in arbitrary units (AU). The scale ranges from 0 (rest) to 10 (maximal effort). It has been determined by Foster to be valid and reliable, with strong correlations between session RPE and heart rate (HR) zones, between *r* = 0.75 and *r* = 0.90. It has been shown to have a correlation with HR in field sports with Borresen et al*.,* (2008), finding a strong correlation between *r* = 0.54 and *r* = 0.78. Halson, (2014), suggested that sRPE was most effective when used in conjunction with an objective marker of physiological response such as heart rate. Some studies use the Borg 6-to-20 scale, (Gomez-Piriz et al*.,* 2011), which can make comparison between studies and results difficult, (Lovell et al*.,* 2013).

It has been suggested in a position paper on training load monitoring in sport that sRPE is not a valid measure of training load in collision sports such as rugby league and rugby union, (Lambert and Borresen, 2010). They observed that this may be due to the physiological stress of frequent collisions and intermittent, high intensity activity which may confound the sRPE method. It has been speculated that sRPE may account for how players feel but underlying physiological stress from collisions may not be well represented using this score. In McLellan et al's., (2011) and Takarada's (2003) studies on the relationship between biochemical and endocrine markers, it was found that there is a correlation between number of tackles in a game and peak creatine kinase activity, which would be in contrast with the position of Lambert and Borresen. This would suggest that sRPE can indeed account for some of the physiological stress as a result of collisions. However, there is a paucity of research on the relationship between creatine kinase and sRPE, so it is difficult to determine if this does indeed effect sRPE validity as a training load monitor in rugby. Although there is ambiguity over how sRPE may account for collisions in collision sports such as rugby union its use in collision sports has been widely corroborated; Clarke et al., (2013) demonstrated that in contact sessions sRPE derived training load significantly correlated to TRIMP (r = 0.69 – 0.91, p < 0.01), when accounting for number of collisions in Canadian Football. Comyns and Flanagan, (2013), have also corroborated the use of sRPE derived training load in rugby union teams as a method of managing injury and performance.

Research has shown a correlation between cortisol and sRPE. Rudolph and McAuley, (1998), identified a positive correlation between rate of perceived exertion and cortisol concentrations (between r = 0.36 and 0.38, p < 0.05). Cortisol has been suggested to have no correlation with tackle load though, so this again confounds the use of using sRPE in collision sports. Lovell et al., (2013) did find a correlation between number of impacts in rugby league training (r = 0.55) and sRPE but this was reduced when intensity was accounted for, in this case as impacts/ minute (r = 0.45). Quarrie et al*.,* (2016), recommend that a comprehensive monitoring system requires the incorporation of subjective and objective data such as sRPE and hormonal responses as well as external load such as number of tackles made or distance run.

A bulk of the research on the correlation between metrics such as testosterone, cortisol or number of tackles; tends to focus on single games or exercise bouts. It has been observed in studies that longitudinal relationships between training load and injury exist. Training load in arbitrary units can be used as an indicator of likelihood of getting injured during training or preparation for sport and competition, (Gabbett et al., 2016). Cross et al*.,* (2016), found that when increases in training loads for a week exceed 1245 AU there was an associated 70% increase in risk of injury. Cross et al*.,* acknowledged that their preseason weekly training loads were low (2175 ± 380 AU) so it was possible they were not habituated to high loads. They also observed in their paper that large week-to-week variances in training load (> 1069 AU) would increase the likelihood of injury by 60%. This study was conducted on senior professional athletes as is the majority of research in training load. It has been observed in rugby union that trained load correlated to overall injury (*r* = 0.82), non-contact injury (*r* = 0.82), and contact injury (*r* = 0.80), (Gabbett and Jenkins, 2011).

Gabbett (2016), suggested that it is not in fact high training load that causes injury rather, an "excessive and rapid increase in training load". This can be responsible for a high proportion of soft tissue injuries. However, high training loads, when prescribed correctly and reached at an appropriate rate, can build physical robustness to withstand injury, (Gabbett et al., 2016). This can be done through use of an acute: chronic training load ratio. Acute training loads can be monitored over ~7 day periods (depending on the length of the micro cycle) and chronic training loads are the rolling average of the previous 3-6 weeks (or a mesocycles) training loads. Banister et al*.,* (1975), proposed that an athlete's response to a training can be considered as the difference between a negative function (fatigue) and a positive function (fitness). In the instance of acute and chronic training loads, acute loads can be considered "fatigue" and chronic training loads can be considered "fitness", (Gabbett, 2016). The ratio of acute to chronic training load is a marker of appropriate training loads, if the acute to chronic training load ratio is kept between 0.8 to 1.3 this is the “sweet spot” and will minimise risk of injury, (Blanch and Gabbett, 2015). It has been observed by Hulin et al*.,* (2013), that an acute: chronic work load ratio in cricket fast bowlers of close to or less 1 indicated a 4% chance of getting injured. Whereas, if the acute: chronic workload ratio was greater than 1.5 the risk of injury increased 2 to 4-fold in the subsequent 7 days.

The use of session rate of perceived exertion is a simple and effective tool that can be utilised by people at all levels of sport. Due to the ease with which it can be administered, and the low cost associated it with it, it is applicable to both high level and amateur sports people. It can be used to predict likelihood of suffering non-contact, more avoidable injuries, as well as being used to monitor and manipulate the training program for athletes, as it will indicate the intensity and volume of training. Due to the inherent ability of athletes to understand and quantify the physiological stress of training that they are exposed to sRPE is a holistic approach to training load quantification and can account for all stressors applied.

It has been shown that session rate of perceived exertion has shown a good relationship with physiological response such as heart rate and training impulse, but the research suggests that the relationship with endocrine markers of training load response in acute or single bouts of exercise is less clear. There is a need for research to determine the relationship over longer time periods as session rate of perceived exertion derived training loads have been shown to be associated to injury and performance over 4-6-week training blocks and longer. With emerging technologies been used in sport science such as GPS, the relationship between sRPE and GPS reported metrics such as distance covered, velocities that distances are covered at, number of accelerations at varying magnitudes and number of collision also needs to be determined. This is due to the relationship between these metrics and performance but also propensity for injury.

Perception of Wellness Monitoring

Similar to sRPE, perception of wellness monitoring is based around the principle that athletes can inherently monitor their physiological environment. Mood and affective state have been shown to be consistent, sensitive early markers of overreaching and overtraining in competitive athletes, (Meeusen et al*.,* 2006). Mood is as a changing, non-specific, psychological disposition to evaluate, interpret, and act on past, current, or future concerns in certain patterned ways, (Parkinson et al*.,* 1996). There are several well-established tools for sport specific psychometric questionnaires to assess how an athlete is coping with training and training load, but most are considered too lengthy to foster compliance with athletes, (Twist and Highton, 2012). It has been found in a survey of current trends of fatigue monitoring by Taylor et al*., (*2012), that the majority (80%) of sport science and strength and conditioning practitioners prefer to use a custom designed form, usually consisting of 4-12 items measured on a 1-5 or

1-10 point Likert scale. Self-reported perceptions of wellness have shown a dose-response relationship to training load in athletes involved in intensive physical training, (Raglin, 2001), and are "efficient, inexpensive and non-invasive" (Main and Grove, 2009).

In a study on measures of fatigue in rugby league players, Twist et al*.,* (2012), found that while neuromuscular performance recovered 48 hours' post-match, perceived fatigue and soreness were still present 48 hours' post. Neuromuscular performance was measured by flight time using a countermovement jump and decreased from 0.61 ± 0.04 s pre-match to 0.59 ± 0.06 s 24 hours post but returned to 0.60 ± 0.05 s after 48 hours ($p = 0.002$) for the forwards group of players. Flight time for backs was 0.66 ± 0.04 s pre-game and reduced to 0.64 ± 0.04 s and 0.64 ± 0.03 s at 24 hours and 48 hours post respectively. Forwards reported muscle soreness pre-game as being 2.0 ± 0.4 (on a scale of 1-5) pre-match and reported muscles soreness of 3.2 ± 0.8 and 3.3 ± 0.9 24 and 48 hours' post-match respectively. Pre-match muscle soreness was reported by backs as being 2.3 ± 0.7 (on a scale of 1-5) and was reported as 3.5 ± 0.7 and 3.2 ± 0.6 24 and 48 hours' post-game respectively. All differences in soreness were significant ($p < 0.05$) pre to post match. Similar increases in self-reported fatigue were found in both playing groups pre to post match. The prolonged increase in muscle soreness and fatigue in rugby players post-game will have implications on training. While their neuromuscular performance has improved, continued feelings of fatigue and soreness may indicate insufficient recovery to facilitate high intensity training.

Gastin et al., (2013), examined perceptions of wellness over a full competitive season and found that perceptions of wellness were affected by the time relative to a game in a microcycle (1-week game to game) and over the larger course of a meso or macrocycle (a phase of the season or the full season). Over the course of a training week, as with Twist et al*., (2012),* it was found that perceptions of pain/soreness were highest 1 day post a game and decreased through the week to game day ($p < 0.001$). In the study, there was observed significant improvements in ratings of wellness after a single week of reduced physical load, in which there was no game and reduced training. This demonstrated the sensitivity of self-reported perceptions of wellness to daily and longer changes in training and competition loads. This is similar to findings by Coutts et al., (2008) who found that there were physiological, performance and psychological improvements after a 7-day training deload in semi-professional rugby players.

It has been shown by Ivarsson et al., (2013), that measures of psychological state were significant predictors of injury in professional soccer players. Four psychometric assessment tools were administered to Swedish Premier League footballers (n=56) and their responses were compared to injury incidence. The psychometric assessment tools were (1) Swedish Universities Scales of Personality, (2) Life Events Survey for Collegiate Athletes, (3) The Hassle and Uplift Scale, and (4) Brief COPE. It was found that trait anxiety, negative-life-event stress and daily hassle were significant ($p < 0.001$) predictors of injury among the players in this study over a 13-week period. Similarly, Laux et al., (2015), determined that the stress-recovery balance as reported by the

RESTQ-Sport questionnaire was a significant predictor of injury in professional football players. The RESTQ-Sport survey was designed based on the assumption that if stress factors in various areas of life are not attenuated by sufficient recovery then there will be a maladaptive psychophysical state, (Kellman & Kallus, 2001). Laux et al*.,* found that general stress and sport specific stress were significantly positively related to injury risk ($p < 0.001$) and that low values on the sleep quality scale were related to a subsequent risk of injury.

Sleep is considered critical to human physiological and cognitive function, (Fullagar et al*.,* 2015), although it's true function remains unclear. Both athletes and coaches agree that sleep is important for athletic performance and recovery, (Venter, 2014), yet there is very little published research on sleep quality and quantity of the athletic cohort. The effect of sleep deprivation on cognitive and physiological performance has been extensively researched and well documented, (Thun et al*.,* 2014). In a study on the effect of sleep deprivation, Reilly and Percy, (1994), found that sleep restriction (3 hours of sleep per night) led to significant decreases ($p < 0.001$) in bench press, leg press and deadlift performance. Interestingly there was no significant change in performance on bicep curl performance ($p > 0.05$) suggesting that fatigue will have a great effect on large muscle groups which will require greater levels of neural drive. There was also a significant effect on mood, vigour and fatigue ($p < 0.001$) resulting from the sleep deprivation. Given the "high motivational component" of weight lifting, this decline in lifting performance may be attributed to the coinciding decline in mood state. There is a limited amount of research into the effects of sleep deprivation on highly trained athletes, as most studies used recreationally trained athletes, (Souissi et al., 2013). This study found that there was decrease in hand grip strength and maximum voluntary contraction after a night of restricted sleep (4 hours sleep). The decrease compared to baselines were 3.1 to 8.4% and 15-24% respectively.

Similar to sRPE, due to the cost effective and invasive nature of perception of wellness profiling it is worthwhile to consider for use with any athletic population. Although some of the psychometric tools available are too time consuming to facilitate athlete compliance, there are several simple and effective questionnaires that can be used. Due to its ability to predict training state over longer time frames (days, weeks or a full season) it can be used to monitor an athlete longitudinally. The possible ability to predict an athlete's propensity to injury at a given time of the season or under a give training load again makes it a useful and worthwhile assessment tool to consider. It has been suggested by Gabbett et al., (2017), that use of perceptual wellbeing when coupled with other measures of training load is an effective way to prepare athletes for competition. The use of standard deviations and Z scores from established base lines on wellness scales is an effective way to determine changes from poor to good states of perceived wellness.

Use of readiness to perform measures or measures of work load can be compared to perceptions of wellness. If work load is low or stable but there is a deviation in perceptions of wellness below baseline then this may be indicative of a maladaptation to training, (Gabbett et al*.,* 2017). If there is a high level of readiness to perform but perceptions of wellness are poor, then psycho social interventions may be necessary. Understanding the interaction of perceptions of wellness and measures of workload and performance will allow for more effective and accurate prescription of interventions and strategies to attempt to optimise athlete wellbeing and readiness to perform. The relationship between perceptions of wellness and musculoskeletal measures, hormonal measures, training load measures as well as neuromuscular measures would be of importance as it would substantiate that individual player or athlete perception of wellness could be indicative of likelihood to perform or under perform as well as likelihood of injury. Due to the ease and cost effectiveness with which wellness measures can be implemented in a training program, if it can be supported by correlation with other objective measures or well validated measures such as training load that it can be integrated with confidence in an athletic performance environment.

Summary

There are many tools that can be used to monitor training response in athletes. Objective measures such as hormonal response, neuromuscular performance, joint mobility and running distance and intensity can be used to monitor an athletes training load response. Also of use in training load monitoring strategy are subjective measures of training load such as session rating of perceived exertion and perception of mood state questionnaires. These subjective measures of internal training load are useful because of their non-invasive and cost-effective nature but they can account for all the variables that affect athletic performance that may be confounded by other measures of training load. While all this information is invaluable to a coach in preparing players for athletic performance, Foster et al*.,* (2017), feel that all of this data needs to be integrated into “unified field theory”.

In order to develop a holistic, “unified” approach to training load monitoring in sports players and athletes, an understanding of all components of training load must be developed with the aim of developing a model that incorporates all physiological, physical and psychological components of training load response. For this to happen an understanding of how all the multivariate and manifold training load responses and monitors interact. As different training modalities will invoke different training strain, no one training monitor method would have the scope to fully describe what an athlete’s response to training. Therefore, a multi modal approach of training load monitoring is essential.

With emerging technologies such as GPS aiding sport scientists and strength and conditioning coaches in understanding the demands of competition and training in different sports, it is crucial that the role they play and how they fit into the overarching training monitoring strategy be determined. This requires that the reliability and validity of such technology be determined as well as how the data that can be reported through it be interpreted and utilised.

Aim

The aim of this study can be divided into three parts. Part one will determine the reliability and validity of 10 Hz GPS units for describing the movement demands of rugby union. Part two of the study will determine the relationship between internal measures of training load and different definitions of high speed running metres. Part three of the study will determine the relationship between different measures of training load over the course of a 11-week international window in Elite U-20 rugby union players.

Study 1

The Inter Unit Reliability and Validity of 10 Hz GPS Units to Measure Rugby Union Specific Movement Demands

Abstract

Purpose: To determine the validity and reliability of 10Hz GPS units.

Methods: Collegiate rugby union players (n = 5) wore 4 GPS units each while completing a simulated rugby union circuit including the most common movement patterns of rugby union, (walking, jogging, running, sprinting, tackling). Data gathered from the units and from criterion measures were used to determine the validity and reliability of the GPS units. 20 data sets (4 per subject) were analysed for the study consisting of 75 trial repetitions (15 per subject).

Results: Distance (m), max velocity (ms^{-1}) and distance covered at a velocity of $>2ms^{-1}$ had a strong ICC between units (>0.9), however distance covered showed a significant difference to the predicted distance covered ($p<0.05$). Max velocity showed no significant difference ($p>0.05$) as did number of tackles. However, number of tackles had a lower but still large ICC (0.665). The number of accelerations in different bands showed a very large ICC (>0.8), however, the CV was poor (29-68%). The CV was good for distance and velocity.

Conclusion: GPS units sampling at 10 Hz are reliable and valid for reporting distance and velocity related metrics, however, may not be as reliable and valid for acceleration and tackle related metrics.

Aim

The aim of this study is to determine the inter-unit reliability of 10 Hz Catapult GPS units, which will be achieved through the comparison of units which were worn concurrently during a simulated rugby union circuit. This study also aims to determine the validity of 10 Hz GPS units compared to criterion measures for measurement of rugby union specific movement demands. This will be achieved by comparing the metrics reported by the GPS to validate measures of the same metric; in this instance velocity as calculated by timing gates, distance as measured by trundle wheel and known number of collisions. This study will examine the first hypothesis;

10 Hz GPS units will not be valid and reliable for determining the movement demands of rugby union.

Methods

Experimental Approach to the Problem

The purpose of this study was to examine if 10 Hz GPS units (Optimeye X4, Catapult Sports, Australia) could measure rugby union specific movements validly and reliably.

Rugby union movement patterns were replicated using a modified game simulation circuit from Singh et al*.,* (2010), which consisted of periods of walking, jogging, striding, sprinting, change-of-direction and tackling. See Figure 3.1 for a schematic of the circuit.

Participants performed 15 repetitions of the circuit and each repetition was performed while wearing four 10 Hz Catapult Optimeye X4 units simultaneously in a bespoke vest under a compression top. Participants wore four GPS units simultaneously to allow for comparison between the metrics measured by each of the units during the trial to determine interunit reliability. Four units were worn simultaneously by each participant during the trial so as to limit the variance in metrics measured which may occur if the trial were to be repeated wearing each unit individually. The GPS units were positioned on the left and right shoulder blades, as well as in line with the spine at least .15m apart so as to reduce inter-unit signal interference. The units on the scapulae were approximately at the level of thoracic vertebra 1. The units on the spine were approximately at the C7 and T8 vertebrae.

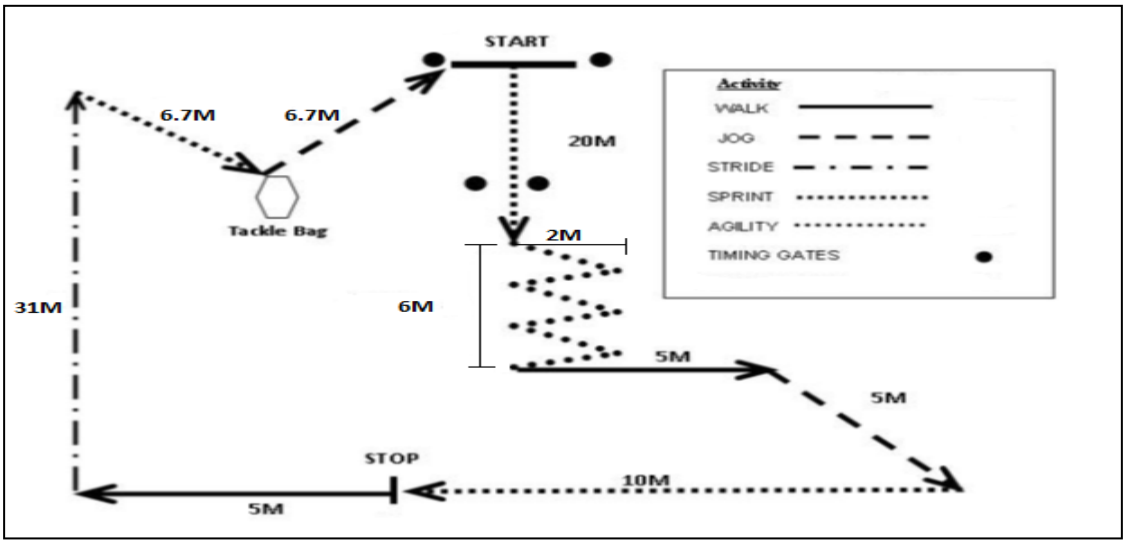

Figure 3.1. Simulated team game circuit with contact (adapted from Singh et al., 2010).

Participants

Participants (n = 5) volunteered for the study. Participants were male, aged 24 ± 0.7 years, mass 85 ± 14 kg, height 1.76 ± 0.08 m (mean ± SD). All participants were collegiate rugby union players in the in-season phase of the season and were free from injury at the time of testing. Participants were informed of all experimental procedures and risks and signed an informed consent before participation. Testing took place on the grass-based rugby pitch in the Institute of Technology, Carlow. Ethical approval was attained from the institute's ethics committee.

Procedures

Participants were required to complete a simulated team game circuit with contact (tackling a pillar bag to the ground), adapted from Singh et al., (2010), which consisted of periods of walking, jogging, striding, sprinting, change-of-direction and tackling (figure 3.1). 15 minutes prior to the commencement of the trial, the GPS units were switched on and left within the border of the testing area to acquire satellite lock.

Prior to commencement of the trial a sport specific warm-up was completed which included three familiarisation laps of the circuit at jogging pace to allow participants to become familiar with the layout of the circuit, followed by three laps performed at the pace as required during the experiment to allow participants to become familiar with the different running intensities used at each of the different sections of the circuit. A total of six familiarisation laps were completed. Participants then commenced the trial which consisted of 15 repetitions of the simulated team game circuit with contact, using a staggered start, (each participant would not start their circuit until the preceding participant had finished theirs). Participants rested between each repetition while the other participants completed their circuit repetition.

Data from the four GPS units on each participant were recorded for the complete trial. Data from timing gates (WITTY, Microgate, Italy), placed at 5m, 10m and 20m at the start of the circuit (as per figure 3.1), were also recorded. Metrics reported from the GPS units were total distance covered (m), maximum velocity (ms^{-1}), distance per velocity band (m), number of accelerations per band (n) and collisions (n). Collisions were simulated by tackling a pillar bag as per Wundersitz et al., (2015), who validated this method of simulating and measuring contact against time motion analysis. Collisions are measured using the built-in 100 Hz accelerometer and 100 Hz gyroscope in both this study and the study by Wundersitz et al.

All metrics were recorded and analysed as the total for the trial, e.g. the sum of the total distance covered across all 15 circuit repetitions, the sum of the total number of collisions across all 15 circuit repetitions etc. Data from timing gates (WITTY, Microgate, Italy), placed at 5m, 10m and 20m at the start of circuit (as per figure 3.1), were also recorded. The metric measured by the timing gates was time (s). 20 sets of GPS data (four per participant for 1 trial of 15 repetitions) were analysed for this study.

Statistical Analysis

Data between each subject's four units were compared using intra class correlations (ICC) and coefficient of variance (CV) to determine reliability between the units over the trial, (Johnston et al*.,* 2014; McFarlane et al*.,* 2015.). ICCs were performed between total distance recorded for all four units per participant, between max velocity recorded for all four units per participant, between distance per velocity band for all four units per participants, number of accelerations per band for all four units per participant and between number of tackles for all four units per participant. Paired T Tests were performed between each unit and the criterion measures to determine validity, (Johnston et al*.,* 2014; McFarlane et al*.,* 2015.). Paired T Tests were performed between known distance of the circuit and the total distance recorded by the GPS units (m). Paired T Tests were performed between known number of simulated collisions and the number of collisions recorded by the accelerometers (n). Paired T Tests were performed between the maximum velocity as calculated from the timing gates to determine validity and the maximum velocity as recorded by the GPS units (ms^{-1}). The formulae used to derive velocity from the timing gates were as follows;

$$\boxed{\begin{array}{c} s = u.t + \tfrac{1}{2}a.t^2 \\ v^2 = u^2 + 2a.s \\ v = u + a.t \end{array}}$$

Where s = distance, u = initial velocity, v = final velocity, a = acceleration and t = time, (Whelan and Hodgeson, 1978). Known variables from the timing gates are distance, initial velocity (as participants make a static start i.e. initial velocity = 0 ms^{-1}) and time as recorded by the timing gates.

The velocity and acceleration bands used here have been used previously by Doğramaci and Watsford, (2006), and are arbitrarily defined to be able to describe distances covered at varying velocities. ICC between each of the 4 units worn by a participant for their trial was determined.

All statistical analysis was performed using SPSS 20.0, (IBM, USA). A correlation grading system involving trivial (0.00 – 0.09), small (0.10 – 0.29), moderate (0.30 – 0.49), large (0.50 – 0.69), very large (0.70 – 0.89), nearly perfect (0.90 – 0.99) and perfect (1.0) scores was used, (Hopkins, 2000; Johnston et al*.,* 2014). The coefficient of variance scores used were poor (> 10%), moderate (5-10%) and good (< 5%), (Hopkins, 2000. Johnston et al*.,* 2014).

Results

There was no significant difference between maximum velocity (MaxV) (ms^{-1}) as recorded by the GPS units and the criterion measure (timing gates) ($p > 0.05$). There was no significant difference between number of tacklers measured by the GPS units and the known number of tackles (n) ($p > 0.05$). There was a significant difference between the known distance and the distance measured by the GPS units (m) ($p < 0.05$).

There were nearly perfect intra class correlations (ICC) for total distance covered and maximum velocity between GPS units for this trial ($r > 0.9$). There was a large ICC between GPS units for number of tackles recorded (n) ($r = 0.66$). There was a very large ICC between GPS units for distances covered in the 0-2 ms^{-1} (m) velocity band ($r = 0.76$) with a good coefficient of variance (CV), (CV = 4.1%). There was a nearly perfect ICC between units for distances covered (m) in the 2-4 ms^{-1} velocity band ($r = 0.97$) with a good CV (2.5%). There was a nearly perfect ICC between units for distances covered (m) in the velocity band 4-6 ms^{-1} ($r = 0.84$) with a moderate CV (8.4%). There was a nearly perfect ICC between units for distances covered above 6 ms^{-1} ($r = 0.96$) with a poor CV (40.6%). There was a very large ICC between units for number of efforts per acceleration band (0-1 ms^2, 1-2 ms^2, 2-4 ms^2, > 4 ms^2) (n) ($r = 0.83 – 0.89$) with a poor CV (10.6 – 22.5 %).

			Distance per Velocity Band (m)				Number of Efforts per Acceleration Band (n)				Tackles
	Total Distance	Max V	0-2	2-4	4-6	>6	0-1	1-2	2-4	4+	N
Mean	2077	6.0	815	782	426	50	14.0	11.0	8.0	10.0	15.0
SD	84	0.1	78	103	122	43	4.0	4.0	5.0	3.0	4.0
CV%	1.2	1.4	4.1	2.5	8.4	40.6	12.5	10.7	22.5	10.6	15.7
ICC	0.91	0.91	0.76	0.97	0.94	0.96	0.85	0.89	0.83	0.87	0.66
Criterion	1504	6.4									15.0
P	0.00	0.63									1.00

Table 3.1. The values for mean measurements of distance, maximum velocity (Max V), distance per velocity band (m), number of efforts per acceleration band (n) and number of simulated tackles made (n) taken from GPS units including standard deviation (SD). The mean coefficient of variance (CV) and mean intra class correlation (ICC) between units for each participant for each metric is shown. Significant differences for given metrics compared to criterion measures is also shown as p value.

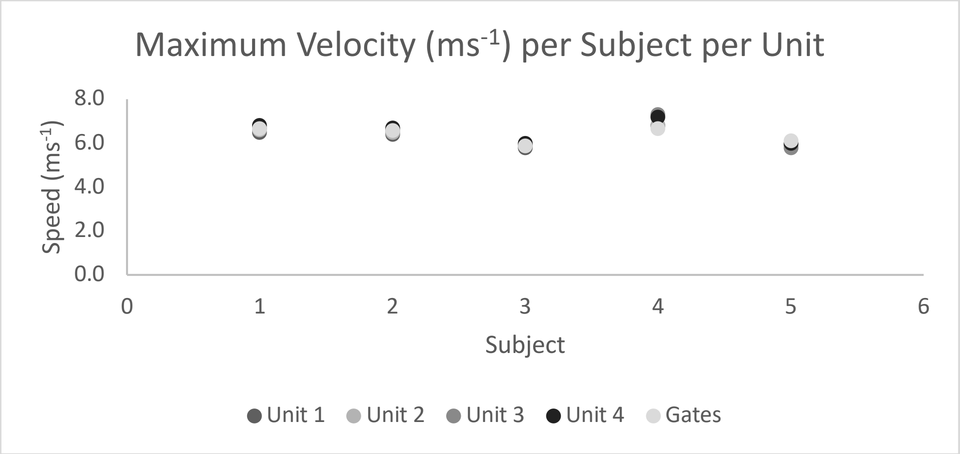

Figure 3.2. The maximum velocity (ms^{-1}) as measured by each unit per subject and as measured by the timing gates.

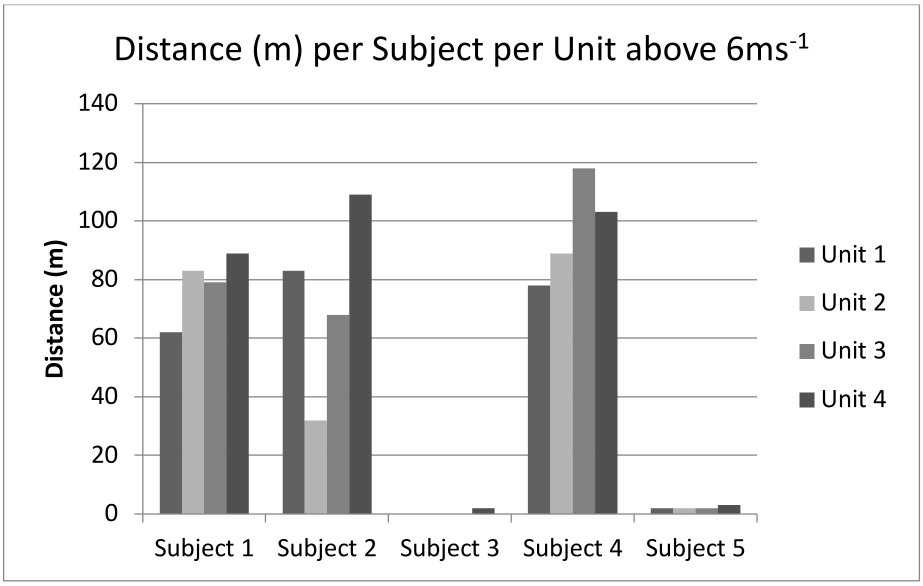

Figure 3.3. The distance travelled (m) reported for each unit while in the high-speed band (> 6 ms^{-1}).

All data were gathered during one testing session with an average horizontal dilution of position (HDOP) of > 1 and an average number of satellites locked of 14.

Discussion

This research has found that GPS data is valid and reliable for measuring most rugby union specific movement demands. The intra class correlation is nearly perfect for distance, maximum velocity and distance covered in velocities bands 2-4 ms^{-1}, 4-6 ms^{-1}, > 6 ms^{-1}. The ICC between units within each participant for these measures is > 0.9 (velocities 0-2 ms^{-1} have an ICC of 0.761 which shows a very large correlation). The high level of correlation is in keeping with previous research, (Varley et al., 2011, Scott et al., 2015). Varley et al*.,* compared GPS units to timing gates when comparing the velocity-based metrics. Where this study contrasts with previous research by Varley et al., is in that the lower velocity band, in this study 0 – 2ms^{-1}, has the lowest ICC at 0.761 compared to the > 0.9 of the higher bands. Traditionally GPS units are more reliable at slower velocities with reliability decreasing as velocity increases according to a review of GPS research conducted by Scott et al., (2015). The ICC is still very large according to the grading system used by Johnston et al., (2014), and as such is still considered reliable at this velocity band.

CV between units within each participant for total distance, maximum velocity and distances covered at 0-2 ms^{-1} and 2-4 ms^{-1} are good, (1.2 – 4.1%) with distances covered at 4-6 ms^{-1} having a moderate CV (8.4%). Scott et al., (2015) and Cummins et al., (2013), both stated that the accuracy is affected by the duration for which an activity is sustained, with lower durations or distances having poorer reliability. Therefore, due to the low amount of distance covered above 6 ms^{-1} (50 ± 43 m) the CV would be affected. It also has been reported previously that accuracy of GPS data decreases with an increase in speed, generally for speeds > 20 kmh^{-1} (> 5.6 ms^{-1}), (Rampinini et al., 2014, Cummins et al., 2013.). The maximum velocities as reported by the GPS units show a nearly perfect ICC (ICC 0.92) between units within each participant so the large variance in mean distances recorded in this speed band (subject 1 covered 78 ± 10 m whereas subject 3 covered 1 ± 1 m, see figure 3.3.) would be the result of inter participant variance in distance covered at this distance.

The ICC for the number of efforts in each acceleration band is nearly perfect with all bands (0-1 ms^{2}, 1-2 ms^{2}, 2-4 ms^{2}, > 4 ms^{2}) having a value of ICC of > 0.8. Again, the CV for these values is poor (12.5- 22.5%) which would be in line with what has been suggested in other papers that current GPS technology cannot report acceleration related data with a high degree of reliability. The ICC for tackle data is large (0.665) while the CV of 15.7% is poor, which would suggest that caution should be used when examining tackling related metrics in rugby union. However, the p value (> 0.05) for tackles as recorded by the GPS units when compared to a known number of completed tackles ($n=15$) show that the units will measure the number of tackles but may not be able to differentiate between tackles of different magnitudes.

This study found that there is a significant difference between the distance recorded by the GPS units and the criterion measures (distance of circuit as measured by trundle wheel (Silverline, England.)), during the trial ($p < 0.05$), although this is likely due to participant's variance while completing the circuit (i.e. sharper turns in change of direction compared to wider turns). It has been found previously by Vickery et al*.,* 2014), that during straight line running that GPS units are valid for measuring distance covered but that when tight or sharp changes of direction such as found in this protocol are used that the validity when compared to criterion measures decreases. However, in this study it is more likely an experimental limitation due to an actual variance in path run by participants and measured path. The study by Vickery et al*,* (2014), indicated that although there were errors in reporting of change of direction the total distance reported was still valid.

There was no significant difference between the maximum velocity achieved as reported by the GPS units and the criterion measure which were timing gates, ($p > 0.05$). Vickery et al*.,* (2014), compared peak velocity as measured by GPS units to timing gates over 40 m and found that GPS units were a valid measure of peak speed when compared to this criterion measure, but this was over a 40m track. In this study the distance of the sprint section is 20m which is closer to the average sprint distance in a rugby union game of 15.3 m as reported by Cunniffe et al*.,* (2009). It was identified by Johnston et al*.,* (2014), that GPS units could in fact over estimate peak velocity reached by athletes when measured over 30m. Findings in relation to results have been equivocal but this study indicates that GPS units can validly measure peak velocity. A limitation of the studies of Vickery et al*.,* Cunniffe et al*.,* Johsnton et al*.,* and this study is that the use of timing gates can only give an average velocity over a given distance so there may be ambiguity resulting because of this. Future research may use timing gates at shorter intervals, such as every 5m instead of 10 m or 20 m so as to more accurately determine velocity.

There was no significant difference between number of tackles as recorded by the 100 Hz accelerometers and the 100 Hz gyroscopes contained in the Optimeye X4 units and the known number of tackles performed. Tackles are determined by the unit by recognition of an impact above a predefined limit and a change in orientation, in this case a forward lean of greater than 60°. The use of a tackle bag has been validated in previous research by Wundersitz et al*.,* (2015), and the present study is in keeping with their findings that GPS technology can be used to quantify number of contacts. As with this study, a limitation is that the tackle contacts are not “live”. Actual tackle events as occur in the game of rugby union would be more valid, however, current validity measures are not suited to such analyses, (Mayagoitia et al*.,* 2001; Wundersitz et al*.,* 2015). This would suggest that GPS units are a valid measure for tackle count and maximum velocity in rugby union but further research using live game tackles is needed to further validate the use of these systems to quantify tackle load. There are other contact or collision event in rugby union such as scrums, rucks and mauls which were not examined in this study and these need to be considered in future research and development of this technology to get a holistic view of external training load and match demands of rugby union.

Conclusions

This research finds that 10 Hz GPS units are a valid and reliable method of quantifying the movement demands and external loads involved with participation in rugby union that were simulated in this study. The current technology can be used to report on velocities and distances with a high degree of reliability and validity, however, the ability to report acceleration and tackle related data still needs to be examined.

It is suggested that from a practical point of view velocities and distances may be used as a measure of the demands placed on a rugby union player. GPS technology will increase in value to sport science and strength and conditioning professionals working within rugby union and team sports in general. At this point however, due to the poor CV values for acceleration and tackle data it would be questionable whether the data reported is reliable with current technology. Consideration will also have to be given to the examination of events such as scrums, rucks, mauls and lineouts and whether they can be quantified and reported by wearable GPS technology in later iterations.

As a result of study 1, the first hypothesis was rejected as the GPS units were demonstrated to be valid and reliable for measuring several rugby union specific GPS metrics in this study. The results displayed ICC values of < 0.9 for distance covered, maximum velocity, and distances covered at a velocity of $< 2ms^{-1}$. The CV for each of these measures was $< 10\%$ with the exception of speeds $> 6ms^{-1}$. The ICC for acceleration metrics was < 0.8, however, the CV was $< 10\%$. The ICC for tackle count was 0.665 with a CV of 15.7%. This study demonstrates that GPS technology can be used to accurately describe distance and velocity related metrics but that acceleration and tackle related metrics are less accurate. The quantification of external training load during rugby union training and match play can be performed using GPS technology. This will allow for a greater understanding of the game for researchers and greater ability to prescribe and manage training load for strength and conditioning and sport science practitioners.

There were several limitations with this study; the small number of participants used here may mean the study is underpowered, but this was due to practical restrictions. There was limited equipment available for the study so with four units per participant only five participants could be used. To maintain homogeneity of conditions such as HDOP and number of satellites locked it was important that all testing be carried out at the same time. Another limitation of the study is the use of a rugby union simulating circuit. For the reliability and validity of GPS to measure the movement demands of rugby union to be determine research should be conducted using live game situations.

Study 2

The Comparison of Definitions of High Speed Running Metres and Their Correlation with Salivary Testosterone, Cortisol, Their Ratio and Session Rate of Perceived Exertion.

Abstract

Purpose: To determine the relationship between individual and arbitrary definitions of high speed running metres and internal measures of training load to determine the optimal definition of high speed running metres.

Methods: Participants (n = 16) who were members of an elite rugby union team sub academy wore GPS units during 6 midweek training sessions. Post training, participants provided salivary samples and session rate of perceived exertions. GPS data were retroactively analysed applying 3 different thresholds of high speed running metres. The thresholds were arbitrary (5 ms^{-1}) and individual (60% VMax and MAS). Saliva samples were analysed for cortisol and testosterone concentrations and their ratios.

Results: High speed running metres as defined by 60% of VMax and MAS had a large, positive correlation with sRPE derived training load (*r* = 0.518 and 0.574, $p < 0.01$)

compared to the arbitrary measure (*r* = 0.431, $p < 0.01$) which had a moderate positive correlation. All other correlations were moderate or trivial.

Conclusion: Individual definitions of high speed running metres having a stronger relationship with internal training load response as observed by its correlation with training load.

Aim

The aim of this study is to compare arbitrary and individual definitions of high speed running metres (HSRM) as measured by 10 Hz GPS units and determine which of the definitions have the strongest correlation to internal measures of training load. The internal measures used in this study are salivary testosterone, cortisol, testosterone: cortisol ratio and session rate of perceived exertion. The use of internal training response to correlate with definitions of HSRM is to bring consensus to the definitions of HSRM by having a physiological basis for their definition. This study will examine the second hypothesis;

There will be no difference in relationship between internal training load measures and arbitrary or individual definitions of high speed running metres in rugby union.

Methods

Experimental Approach to the Problem

The purpose of this study was to determine if three distinct definitions of high speed running metres are significantly different from each other and if they correlate with internal measures of training load. High speed running metres are the distance covered above a given velocity threshold, (Reardon et al*.,* 2015). The definitions of high speed running metres used were 5.0 ms^{-1} (arbitrary value), 60% of maximum velocity (60% VMax) (individual value) which are both suggested by Reardon et al., (2015) and the novel definition of HSRM as suggested by this study of maximum aerobic speed (MAS).

10 Hz GPS units (Optimeye X4, Catapult, Australia) were worn by participants (n = 16) during midweek training sessions (n = 6). 6 training sessions were used in order to get a larger data set to allow for greater comparison of high speed running metres. All training sessions were on a Wednesday between 1030 and 1200 with a duration of 74 ± 9 mins. 16 sets of data were recorded for each session with 96 data sets recorded in total.

Within 10 minutes after cessation of training, (Gaviglio and Cook, 2014), salivary samples were obtained, and players provided sRPE on a scale of 1-10, (Foster et al*.,* 2001).

High Speed Running Metre Thresholds

Raw data were gathered for participants over six midweek training sessions. Three definitions of high speed running metres were retroactively applied to each training session's data to determine how much distance above each velocity threshold was covered. The distance covered above each velocity threshold were the metrics reported. The thresholds (all in ms^{-1}) were as follows;

Arbitrary threshold: 5.0 ms^{-1}

Individual threshold: 60% of individual maximum velocity (60% VMax)

Individual threshold: individual maximum aerobic speed (MAS)

60% of an individual's maximum velocity was determined by retroactively examining GPS data gathered from all six training sessions using Sprint 5.1 software, (Catapult Sports, Australia), and determining the maximum velocity that each individual achieved in any session. 60% of this velocity in ms^{-1} was then applied to all sessions. The Sprint 5.1 software then reported distance covered above each participant's 60% VMax threshold. This is in accordance with the protocol used by Reardon et al*.,* to determine 60% VMax.

Maximum aerobic speed (MAS) was determined by use of the YoYo Intermittent Recovery Test 1 (YYIRT1), whereby the velocity in ms^{-1} in the last shuttle reached by the individual is their maximum aerobic speed. YYIRT1 has been shown to have a good correlation with VO_2Max, (Krustrup et al., 2003). Two days prior to the commencement of the study, all participants performed a YYIRT1 to volitional exhaustion as part of their normal preseason fitness testing battery. Each individuals MAS was applied using Sprint 5.1 software to the raw data and distance covered above this threshold in each session was reported.

An arbitrary threshold of 5.0 ms^{-1} was applied to each participant's raw data and distance covered above this velocity was reported for each individual.

Participants

Participants (n = 16) volunteered for this study. Participants were male, aged 19.1 ± 0.2 years, mass 99.8 ± 10.0 kg, height 180.8 ± 20.0 cm. All participants were members of a professional rugby union teams' sub academy, had a minimum of two years' experience of representative rugby and were in the preseason phase of the season. Due to participants having a minimum of 2 years of representative rugby they were well habituated to using a sRPE scale. Players were all injury free at the commencement of the study. Participants were informed of all experimental procedures and risks and signed an informed consent before participation. Testing took place on the artificial surface (4G Astro Turf) rugby pitch at Donnybrook Stadium, Dublin. Ethical approval was attained from the institute's ethics committee.

Procedures

Participants wore the Catapult Optimeye X4 units in specially fitted vests. Participants wore the same GPS unit for every training day so as to ensure consistency of data collection. 15 minutes prior to the commencement of training, the GPS units were switched on and left within the boundaries of the training pitch to acquire satellite lock.

Participants completed the training session as normal. The focus of the midweek training sessions was tactical and technical development. A skill-based training session was chosen because of the specificity of the training session to the actual game requirements, (Gaviglio and Cook, 2014). Contact was limited during these training sessions but due to the nature of the game there were still minor collision events such as bag hits or shoulder bumps. 10 minutes' post training participants provided a passive drool sample into a plastic collection tube (SaliCap, IBL, Switzerland). Participants were asked to provide a session rate of perceived exertion at the same time as the saliva sample. A modified CR10 Borg scale, (Foster et al*.,* 2001), was used to gather sRPE from participants, (*figure 4.1.*). Individual sRPE was multiplied by session duration (minutes) to obtain training load in arbitrary units (AU).

Saliva samples were stored at -20^{o}c until the end of the 6 weeks' study period and then were analysed in batch in the Dargan Centre at the Institute of Technology, Carlow. Testosterone and cortisol levels in the saliva samples were analysed using enzyme linked immunosorbent assay (ELISA), (IBL, Switzerland). Testosterone was measured in pmol/L and cortisol was measured in nmol/L as per Maso et al., (2004). All samples were prepared in a laminar flow cabinet to ensure sterility of the samples prior to analysis in a VersaMax plate reader (Molecular Devices, CA, USA) using SoftMax software (Molecular Devices, CA, USA).

SRPE	
1	Rest
2	Very, very easy
3	Easy
4	Moderate
5	Somewhat hard
6	Hard
7	
8	Very Hard
9	
10	Maximal

Figure 4.1. Modified Borg CR10 Scale, (Foster et al., 2001).

GPS data were retroactively analysed using Sprint 5.1 software (Catapult Sports, Australia), applying the three different thresholds of high speed running metres to determine distances covered above each individual velocity threshold and the arbitrary velocity threshold by each participant.

Testosterone, cortisol, their ratio and training load were the internal measures of training load. These were compared to each definition of HSRM to determine if there was a correlation between any or all of them that may indicate the most valid measure of HSRM.

Statistical Analysis

A repeated measures ANOVA was performed between the mean value for each velocity threshold to determine if there was a significant difference between each threshold. Data were analysed for normality, followed by a Spearman's rank correlation coefficient which was used to determine the correlation between each of the internal measures of training load, (testosterone, cortisol, their ratio and session rate of perceived exertion) and the distances covered above each of the velocity thresholds. A correlation system involving trivial (0.00 – 0.09), small (0.10 – 0.29), moderate (0.30 – 0.49), large (0.50 – 0.69), very large (0.70 – 0.89), nearly perfect (0.90 – 0.99) and perfect (1.0) scores was used, (Hopkins, 2000; Johnston et al, 2014.) Data gathered from the GPS units were analysed using SPSS 20.0 (IBM, USA).

Results

There was a significant difference between each threshold of high speed running metres as determined by the ANOVA, ($F(2,188)=30.083$, $p<0.05$).

There was a moderate, significant, positive correlation between testosterone and distance above 5.0 ms^{-1}, ($r = 0.367$, $p < 0.05$). There was a moderate, significant, positive correlation between testosterone and distance above 60% VMax, ($r = 0.450$, $p < 0.01$). There was a moderate, significant, positive correlation between testosterone and distance above MAS, ($r = 0.408$, $p < 0.01$).

There was a trivial, non-significant, positive correlation between cortisol and distance above 5.0 ms^{-1}, ($r = 0.062$, $p > 0.05$). There was a trivial, non-significant, negative correlation between cortisol and distance above 60% VMax, ($r = -0.056$, $p > 0.05$). There was a trivial, non-significant, negative correlation between cortisol and distance above MAS, ($r = -0.042$, $p > 0.05$).

There was a moderate, significant, positive correlation between testosterone to cortisol (TC) ratio and distance above 5.0 ms^{-1}, ($r = 0.423$, $p < 0.01$). There was a moderate, significant, positive correlation between testosterone to cortisol (TC) ratio and distance above 60% VMax, ($r = 0.328$, $p < 0.05$). There was a moderate, significant, positive correlation between testosterone to cortisol (TC) ratio and distance above MAS ($r = 0.378$, $p < 0.01$).

There was a moderate, significant, positive correlation between training load and testosterone, (*r* = 0.353, p < 0.01). There was a trivial, non-significant, negative correlation between training load and cortisol, (*r* = -0.41, p > 0.05). There was a weak, small, positive correlation between training load and testosterone to cortisol ratio, (*r* = .0.268, p < 0.01).

There was a moderate, significant, positive correlation between training load and distance above 5.0 ms^{-1}, (*r* = 0.431, p < 0.01). There was a large, significant, positive correlation between training load and distance above 60% VMax, (*r* = 0.518, p < 0.01). There was a large, significant, positive correlation between training load and distance above MAS, (*r* = 0.574, p < 0.01).

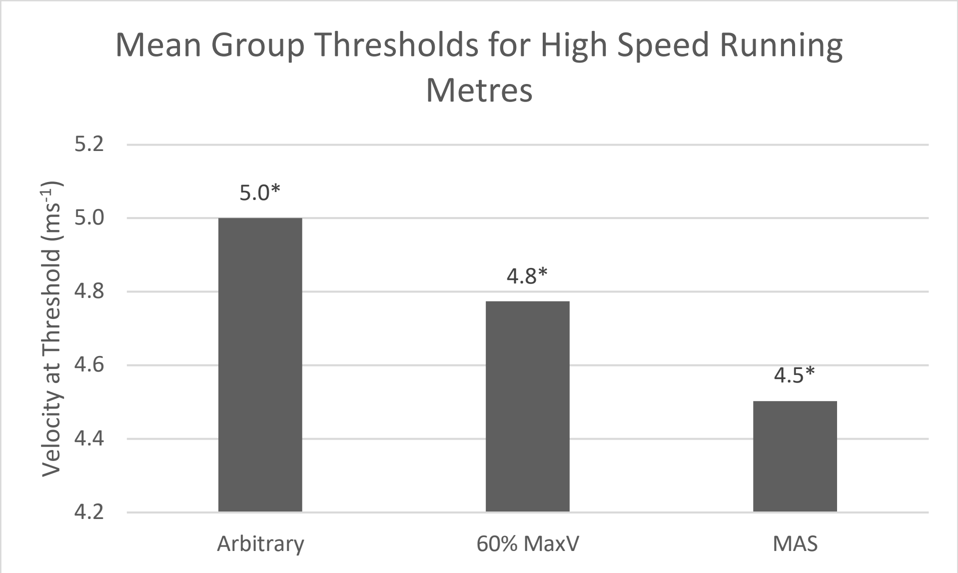

Figure 4.2.

Mean group velocities (ms^{-1}) for the three thresholds of high speed running metres (arbitrary, 60% VMax, MAS).

**denotes a significant difference between thresholds (F(2,188)=30.083, p<0.05).*

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
T (pmol/l)	846.7	1563.7	1193.7	2235.8	1040.9	475.7
C (nmol/l)	7.7	14.8	9.110	5.0	10.3	6.2
TC	113.1	142.9	262.4	338.2	217.6	120.6
TL (AU)	234	505	366	642	443	293
5.0 ms^{-1} (m)	51	112	203	354	157	132
60% VMax (m)	70	191	231	543	203	188
MAS (m^1)	94	196	733	642	254	237

Table 4.1. Mean group values for testosterone (T)(pmol/l), cortisol(C) (nmol/l), testosterone to cortisol ratio (TC), training load (TL)(AU) and distance above each threshold, (5.0 ms^{-1} (m), 60% VMax (m), MAS (m)) per week.

	T	C	TC	TL
5.0 ms^{-1}	0.367*	0.062	0.378**	0.431**
60% VMax	0.450**	-0.056	0.328*	0.518**
MAS	0.408**	-0.042	0.413*	0.574**

Table 4.2. Correlations between each of the internal measures of training load monitoring (testosterone (T), cortisol (C), testosterone: cortisol ratio (TC) and training load (TL) and each of the definitions of high speed running metres (5.0 ms^{-1}, 60% VMax, MAS)) (r).

**Denotes a statistical significance ($p < 0.05$)*

***Denotes a statistical significance ($p < 0.01$)*

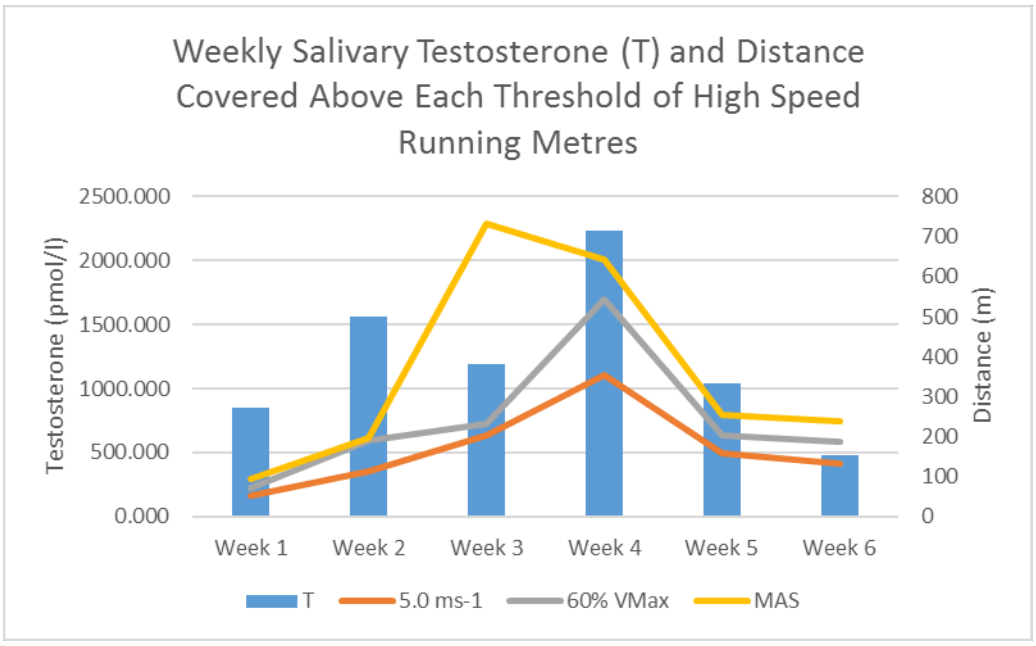

Figure 4.3. Mean group values for all weeks comparing testosterone (T)(pmol/l) to distances above each threshold of high speed running metres (5.0 ms^{-1}, 60% VMax, MAS)(m).

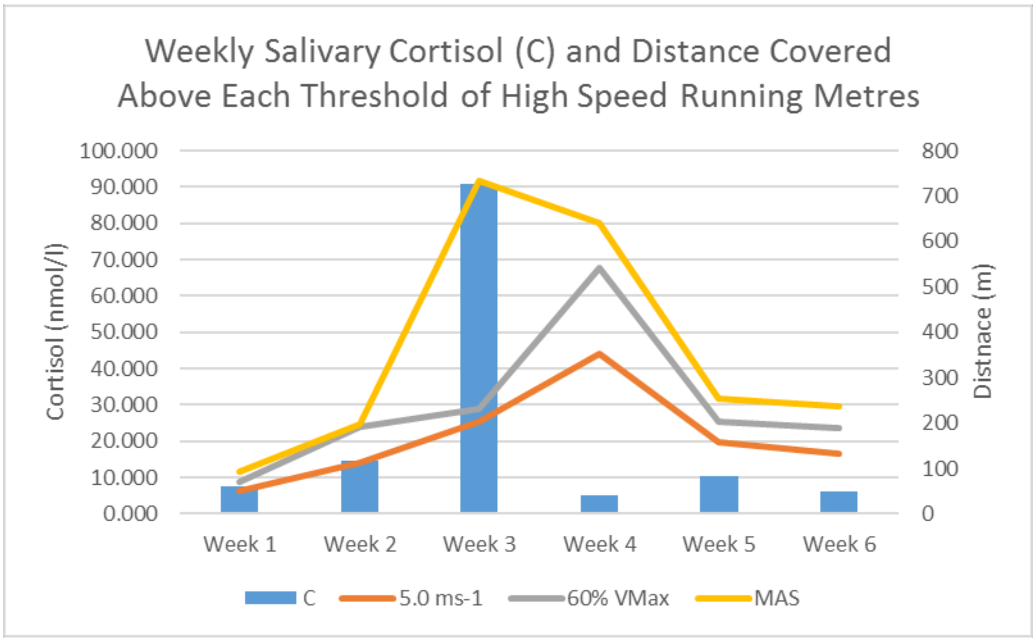

Figure 4.4. Mean group values for all weeks comparing cortisol (C) (nmol/l) to distances above each threshold of high speed running metres (5.0 ms^{-1}, 60% VMax, MAS)(m).

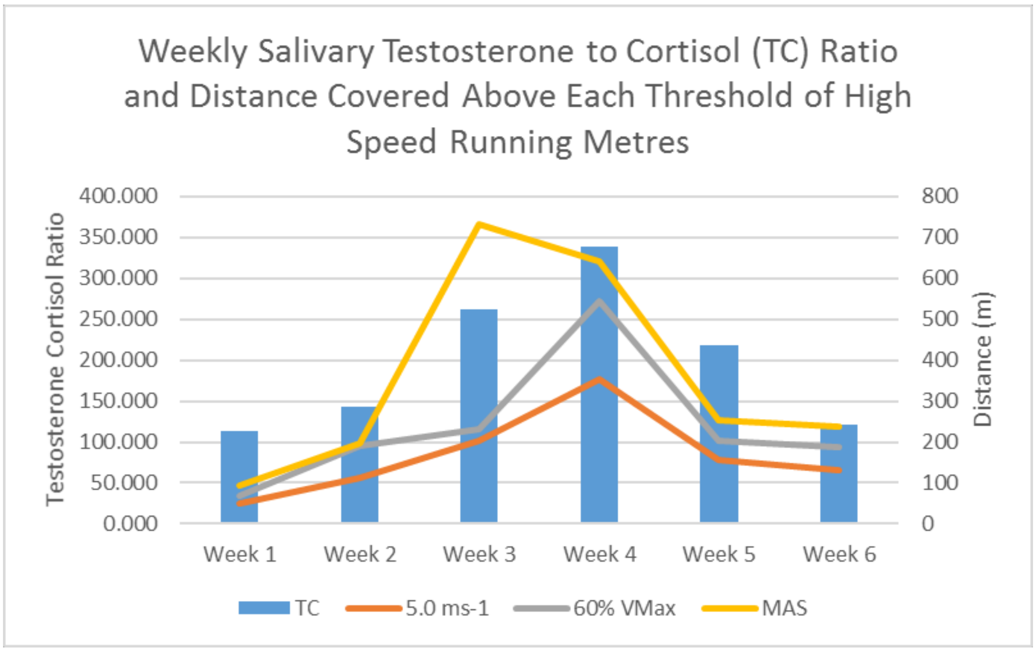

Figure 4.5. Mean group values for all weeks comparing testosterone to cortisol (TC) ratio to distances above each threshold of high speed running metres (5.0 ms^{-1}, 60% VMax, MAS)(m).

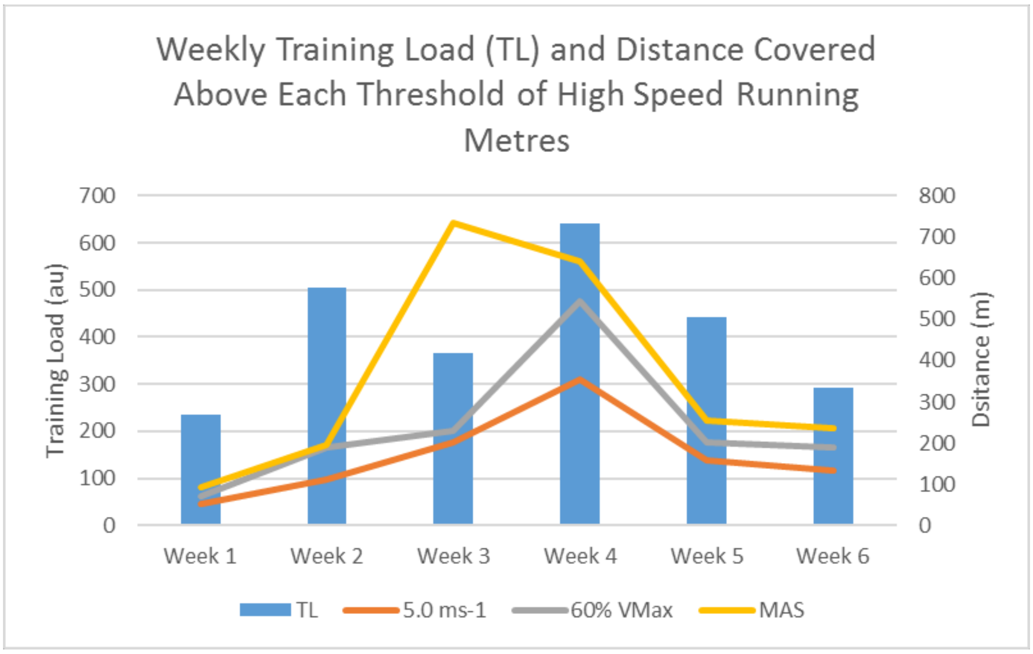

Figure 4.6. Mean group values for all weeks comparing training load (TL) to distances above each threshold of high speed running metres (5.0 ms^{-1}, 60% VMax, MAS)(m).

Discussion

This study shows that there is a significant difference between the mean group thresholds of high speed running metres that were examined here, (F(2,188)=30.083, $p<0.05$). This demonstrates that each threshold should be examined and considered separately as they may have differing correlations with other measures of training load. This study also shows that there is a relationship between testosterone response and the high-speed running metres definitions, with the individual markers (60% VMax and MAS) having a larger correlation than the arbitrary marker (5.0 ms^{-1}). Testosterone has a moderate correlation with distance above 5.0 ms^{-1}, 60% VMax and MAS of r = 0.367, r = 0.450 and r = 0.408 respectively. Hayes et al., (2015), in a meta-analysis of endocrine response to aerobic training, identified that salivary testosterone generally increased after aerobic based exercise with a standard difference of means of 0.891 (95% CI, 0.018 - 1.765). Their findings were that generally testosterone increases after an aerobic based exercise session. The only study that found a decrease used golf as an aerobic intervention, (Doan et al., 2007). A round of golf may not have been aerobically taxing enough to illicit a physiological response and due to the length of the intervention, which was 36 holes of golf, the change in testosterone may have been due to diurnal variation. It has also been shown that testosterone will increase with anaerobic work, with an increase of 20% in testosterone concentrations observed by Sgrò et al., (2014), after 30 minutes of steady state exercise showing that testosterone will increase in response to anaerobic activity as well.

The greater correlation with distance covered above 60% of maximum velocity as opposed to maximum aerobic speed may be due to the higher threshold at 60% of VMax. 60% of VMax has a 4% higher threshold and therefore it can be posited that players are incurring greater anaerobic stress which may result in the greater testosterone response. Although this is confounded by the highest threshold (arbitrary threshold of 5.0 ms^{-1}), having the lowest correlation with testosterone response. This may be due to a change in metabolic demands as the intensity increases further.

With the moderate correlation between testosterone response and the individual thresholds of high speed running metres, it would suggest that the individual thresholds may be a good indicator of physiological response to training and therefore should be considered for use as a threshold for high speed running metres in both team and research-based settings. All thresholds have moderate correlations with the two individual thresholds having a slightly stronger correlation but there is still further research needed to clear up this ambiguity. This is in keeping with previous studies where aerobic training showed an increase in testosterone immediately post. As maximum aerobic speed has been shown to be related to distance covered in a game, (Swaby et al*.,* 2016), which can also be a key performance indicator for success in a game or competition then it’s use as a measure of HSRM is intuitive. However, this study only compared testosterone response to a post training sample. Further studies should consider the use of pre and post training testosterone sampling so as to account for any diurnal or rhythmic variations in endocrine response. A comparison between change of testosterone from the training intervention would lend more credence to the study.

The negligible correlations with cortisol are in contrast to research that has been found previously. Hayes et al*.,* (2015), in their meta-analysis generally found that aerobic training results in an increase in salivary cortisol post exercise (SDM 1.091, 95% CI 0.067 - 6.148). It has been suggested that aerobic exercise will have a greater increase in salivary cortisol due to decreases in glucose associated with longer duration exercise, however, in this study the intensity may not have been high enough and the recovery time between bouts of high speed running metres may have been long enough to allow for full metabolic recovery, (Reilly and Gilbourne, 2003). It has been found by Lo et al., (2016), that there can be a suppressive effect on cortisol depending on running intensities, with submaximal intensities showing decreases in cortisol immediately post exercise but running at maximal intensities can increase cortisol immediately post. As the high-speed running metre thresholds used here are submaximal this may account for the lack of a significant correlation between the distances above each threshold and salivary cortisol response.

McLellan et al*.,* (2011), found that there was no correlation found between cortisol level post-game and the numbers of tackles made in a rugby league game. The number and magnitude of collisions in a training session may be a confounding variable that would affect the cortisol response to and correlation with high speed running metre distance. It has been found by McLellan et al*.,* (2011), and other studies, (Cormack et al*.,* 2008; Elloumi et al*.,* 2003), that there is an increase in cortisol pre and post participation in collision sports, but this may not be as a result of the multitude of different stressors involved in the game, such as anticipatory anxiety, blunt force trauma or metabolic stress. Although contact was limited in these sessions to “grab-tackles” and bag hits and bumps there was still a collision element in the game, which may have had a confounding effect on cortisol's relationship with the high speed running metre metrics.

The largest correlations between the definitions of high speed running metres and an internal measure of training load were found between training load (AU) and the distances. The correlations between training load and distance above 5.0 ms^{-1}, 60% VMax and MAS were r = 0.431, r = 0.518 and r = 0.574 respectively. This shows a moderate correlation between the arbitrary threshold and training load and a large correlation between the individual thresholds and training load. This may be due to the fact, as previously stated, that ratings of perceived exertion are based on the understanding that athletes can inherently monitor the total physiological stress placed on their bodies during exercise, (Sorensen and Lambert, 2009). Session rate of perceived exertion will therefore be a holistic measure of all the internal responses to training regardless of the source of the stress e.g. blunt force trauma of tackle or collision events or the metabolic stress of different intensities of running.

Lovell et al*.,* (2013), found that the there was a correlation (r = 0.55) between collisions in a game and sRPE so it can be held that sRPE will account for the impacts in the training session as the sessions were generally skill based with less elements of contact. This would reduce the confounding affect that may have affected the correlation between cortisol and distances covered above each measure of high speed running metres.

The individual markers of high speed running metres have the largest correlations with the measures of training load. Maximum Aerobic Speed as a definition of HSRM shows the best correlation with testosterone to cortisol ratio and training load post training, while having a moderate correlation with testosterone concentration post training. 60% Vmax has a better correlation with testosterone concentration post training, but both have moderate correlations, (r = 0.408 and r = 0.450 respectively). There was a trivial negative correlation with distance above MAS and cortisol. The individual value showed the smallest correlation with testosterone response and training load but had the only (again trivial) positive correlation with cortisol (r = 0.062).

Conclusions

This study would suggest that the use of individual markers to define high speed running metres in future studies and in practical, team sport environments when using GPS units. This may give a greater insight into the physiological response of players or athletes to the external training load involved in rugby union. As players perform 5.6 to 9.7% of their movement at high speed and a further 2.0 to 3.3% at very high speed, (Gabbett, 2015), it is important to quantify how much distance they cover at these velocities but also to have a physiological, individualised basis for each threshold. This will be of benefit in devising recovery strategies and protocols in team sport environments as well helping researchers better understand the demands of the game.

The use of biomarkers to corroborate individual thresholds of high speed running metres or different intensity activities is intuitive. However, the biomarkers used may need to be reconsidered and be more sport specific. Due to the confounding effect of collisions on cortisol there may still be some ambiguity about its usefulness as a biomarker of training load in a collision sport such as rugby union, it could be effectively applied to non-contact sports like football (soccer). While it could be expected that a stress hormone like cortisol would be affected by collisions it needs to be further studied to understand it's role in collision sports and may need to be examined in conjunction with another biomarker such as creatine kinase. Testosterone shows a strong correlation with both training load and the individual definitions of HSRM but may also be affected by physical aggression or confrontation like that found in rugby union, (Gaviglio et al., 2014).

As maximum aerobic speed has been used in this study and is physiologically defined as the lowest speed at which VO2max has occurred, (Baker, 2011), the use of a biomarker of oxidative stress may be used to measure the correlation of HSRM distance and biological stress. Protein carbonyls have been used as a measure of oxidative stress, (Varamenti et al., 2013), and may be used to determine if maximum aerobic speed is a valid measure of high speed running metres.

As rugby union is a primarily an anaerobic sport, (Duthie et al*.,* 2003), the individual thresholds used to determine high speed running metres may be too slow. Perhaps using lactate threshold as a measure of high speed running metres may be worthwhile to consider in rugby union, as blood lactate concentrations post-game have indicated the contribution of anaerobic glycolysis in rugby union, (Deutsch et al., 2010). A higher percentage of maximum velocity could be utilised as well, higher than the 60% VMax suggested by Reardon et al*.,* (2015). 70% of maximum velocity was suggested as a threshold for very high-speed running by Gabbett (2015) and the relationship between distance covered above this threshold and physiological response could be of interest to researchers and practitioners alike. This study corroborates the use of individual thresholds of high speed running metres when using a physiological basis. Further research is needed to determine which may be the most appropriate thresholds or biomarkers for a given sport.

As a result of study 2, the second hypothesis was rejected as the different definitions of training load demonstrated a moderate to strong correlation with the definitions of high speed running metres in this study. The results displayed a large correlation between distance covered above maximum aerobic speed and training load (r = 0.574) and distance above 60% of maximum velocity and training load (r = 0.518). There was a moderate correlation between testosterone concentration and distance covered above 60% maximum velocity (r = 0.450), testosterone concentration and distance covered above maximum aerobic speed (r = 0.408), testosterone to cortisol ratio and distance covered above maximum aerobic speed (r = 0.413), and training load and distance covered above 5.0 ms^{-1} (r = 0.431). This study displays that there is a relationship between training load response and distance above definitions of high speed running metres with the individual measures of training load demonstrating a larger correlation with training load response than arbitrary measures of training load. The use of individual measures of training load to quantify high speed running metres for rugby union players allows for determination of an individual athletes training load response so as to best prescribe training or recovery strategies post training and competition.

There were several limitations in this study. The comparisons between the hormonal measures and high speed running metres were only between post training samples. Further studies where practically applicable should consider using pre and post training samples so that changes over a training session may be compared. Use of a wider, more heterogenous group should be used. This study used 14 forwards and 2 backs, future studies should consider using a more even split of backs and forwards so that groups may be split into high speed and low speed groups for comparison.

Study 3

Measures of Training Load Response in Elite U20s Rugby Union Players During a Period of Intensified Competition

Abstract

Purpose: To compare objective and subjective training load measures during a period of international competition and determine how they relate and respond during training and competition.

Methods: Participants (n=5) 16 were monitored during the 2017 under 20s Six Nations using objective and subjective measures of training load with 15 training load measures in total. All measures were taken in the morning on a midweek training day, except for acute training load, chronic training load and acute chronic work ratio which were taken for the full week.

Results: There were moderate, positive correlations between stress and body weight, stress and soreness, groin squeeze and countermovement jump and knee to wall difference and countermovement jump. There were moderate, negative correlations between countermovement jump and mood and sleep. There are strong, positive correlations between sleep and mood, stress and fatigue and fatigue and soreness. All other correlations were trivial.

Conclusion: Perception of wellness measures are sensitive to physiological, neuromuscular or musculoskeletal responses to training load. This correlation may be indicative of capacity to perform, likelihood to get injured or recovery from a training or competition bout. More cost-effective measures such as groin squeeze may be able to indicate capacity for neuromuscular performance.

Aim

The aim of this study is to compare objective and subjective measures of training load response over an 11-week period of international competition and determine if there is a relationship between each of the measures of training load.

There will be no relationship between any of the objective and subjective measures of training load in Elite U-2O rugby union players.

Methods

Experimental Approach to the Problem

The purpose of this study was to determine the relationship between the different measures of training load and their response in Elite U20 rugby union players. The measures examined were training load (acute, chronic and their ratio), musculoskeletal assessment measures (counter movement jump, groin squeeze, knee to wall and body mass), wellness measures (stress, fatigue, mood and sleep quality) and hormonal measures (testosterone). Musculoskeletal assessment measures, wellness measures and hormonal measures were taken midweek, in the morning before training commenced, as part of their usual daily monitoring. Training load measures were taken for the full week.

Objective measures were all measured prior to training in the mornings between 0700-0730 in the gym. Measures were taken on the first training day of the week (Monday or a Tuesday depending on whether there was a game on the Saturday or Sunday). Acute, chronic and acute: chronic training load ratio was measured as the training load for the preceding 7 days, 4 weeks and their ratio respectively. The objective measures included countermovement jump, groin squeeze, knee to wall and saliva samples (testosterone). Subjective measures included self-reported stress, fatigue, mood, sleep quality and acute, chronic and acute: chronic training load ratio. All measures were taken on a single day in the training week and compared against each other for that day as being representative of their training load response.

Wellness Measures

Stress

Participants self-rated their current perceived stress levels on a scale of 1-10, with 1 being the lowest level of stress and 10 being the highest.

Fatigue

Participants self-rated their current perceived fatigue levels on a scale of 1-10, with 1 being the lowest level of fatigue and 10 being the highest.

Soreness

Participants self-rated their current perceived soreness levels on a scale of 1-10, with 1 being the lowest level of soreness and 10 being the highest.

Mood

Participants self-rated their current perceived mood levels on a scale of 1-10, with 1 being the lowest level of mood and 10 being the highest.

Sleep Quality

Participants self-rated their perceived sleep quality level for the previous night's sleep on a scale of 1-10, with 1 being the lowest level of sleep quality and 10 being the highest.

Hormonal Measures

Participants provided passive drool samples into a plastic collection tube, (SaliCap, IBL, Switzerland). Participants were awake for at least 60 minutes at the time of sampling and had refrained from consuming any food or liquids for at least 30 minutes prior. The samples were then stored at -20^{o}c until they were analysed in batch at the end of the 11-week study period. Analysis was carried out in the Dargan Centre, Institute of Technology, Carlow. Testosterone (T) in the saliva samples was analysed using enzyme linked immunosorbent assay (ELISA).

Musculoskeletal Assessment Measures

Body Mass

Body mass (BM) was measured using a digital weighing scales, (Seca, Germany). Participants removed shoes and tops and stepped on the scales, their mass was measured to the nearest one decimal place (kg).

Groin Squeeze

Participants used a sphygmomanometer, (Welch Allyn, NY, USA) to determine adductor strength by performing a groin squeeze (GS) assessment. The sphygmomanometer was pre-inflated to 20 mmHg, then participants lay supine, with their knees and hips flexed to 45^{o}, (Delahunt et al*.,* 2011). Participants then placed the sphygmomanometer between their thighs, at mid-thigh level and squeezed maximally. Their groin squeeze was recorded as the highest value observed on the dial in mmHg.

Knee-To-Wall

The ankle range of motion of participants was determined using a knee-to-wall (KTW) test. Participants placed their foot on a ruler on the ground, perpendicular to the wall and touching the base of the wall. Participants brought their knee to the wall while keeping their heel on the ground. Participants brought their foot out as far from the wall as possible while keeping their heel flat on the ground. The furthest distance the tip of their hallux was from the wall while still being able to keep their heel flat on the ground was recorded in cm. This was performed for both the left (KTW_L) and right (KTW_R) ankle and the difference between both (KTW_Diff) was determined also.

Counter Movement Jump

Participants maximum counter movement jump (CMJ) height was recorded using a jump mat, (Globus, Italy), after performing an individual warm up as prescribed by the strength and conditioning and physiotherapy staff. Participants stood on the jump mat, with their arms akimbo, and were required to perform 3 maximal jumps with straight legs and hands remaining on hips throughout. Their CMJ was recorded as their highest jump of the three repetitions in cm.

Training Load

Participants provided session rate of perceived exertion on a scale of 1-10 after each training session during the week, with 1 being the easiest and 10 being the hardest. sRPE was then multiplied to give training load for that session in arbitrary units (AU). The training load in arbitrary units for the week was then the sum of every training session. Acute training load (ATL) was the total training load in arbitrary units for one week. Chronic training load (CTL) was the average weekly training load over a four-week period. Acute to Chronic training load work ratio (ACWR) was calculated by dividing the acute training load by the chronic training load.

Participants

Sixteen participants volunteered for this study. Participants were male, aged 19.1 ± 0.2 years, mass 99.8 ± 10.0 kg, height 180.8 ± 20.0 cm. All participants were members of a professional rugby union teams sub academy and an U20 national squad. All participants had a minimum of two years' experience of representative rugby union and were in the in-season phase of the season. Testing took place during the 2017 U20s Six Nations competition. Participants were informed of all experimental procedures and risks and signed an informed consent form before participation. All data was collected at Donnybrook Stadium, Dublin. Ethical approval was attained from the institute's ethics committee.

Statistical Analysis

Correlations were determined between each of the metrics gathered in this study for a total of 105 correlations. Correlations were determined between each of the wellness measures and between each of the wellness measures and each of the musculoskeletal measures, training load measures and hormonal measures. Correlations were determined between each of the musculoskeletal measures and between each of the musculoskeletal measures and each of the wellness measures, training load measures and hormonal measures. Correlations were determined between each of the training load measures and between each of the wellness measures, musculoskeletal measures and hormonal measures. Correlations were determined using between the hormonal measure and each of the wellness measures. musculoskeletal measures and training load measures. Data gathered were analysed using SPSS 20.0 (IBM, USA). A correlation system involving trivial (0.00 – 0.09), small (0.10 – 0.29), moderate (0.30 – 0.49), large (0.50 – 0.69), very large (0.70 – 0.89), nearly perfect (0.90 – 0.99) and perfect (1.0) scores was used, (Hopkins, 2000; Johnston et al*.,* 2014).

Results

There were moderate positive correlations between stress and body mass (0.340), stress and soreness (0.461), knee to wall difference and countermovement jump (0.303), groin squeeze and countermovement jump (0.335), chronic training load and body mass (0.313), knee to wall right and body mass (0.314), and chronic training load and acute training load (0.330).

There were moderate negative correlations between countermovement jump and mood (-0.329), countermovement jump and sleep (-0.336), knee to wall difference and knee to wall right (-0.455), and chronic training load and acute to chronic training load ratio (-0.339).

There were large to very large positive correlations between sleep and mood (0.542), stress and fatigue (0.538), fatigue and soreness (0.579), knee to wall left and knee to wall right (0.511), acute training load and acute to chronic training load ratio (0.729).

All other correlations were small or trivial.

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11
ATL	2246	2173	1982	2387	2036	1875	1809	2056	1987	2029	1424
CTL	1371	1603	1856	2197	2145	2070	2027	1944	1932	1970	1874
ACWR	1.61	1.34	1.09	1.09	0.95	0.89	0.88	1.06	1.05	1.05	0.76
CMJ	49.0	50.6	49.3	51.0	50.1	51.1	50.7	49.1	48.4	48.3	50.3
BM	99.8	100.4	99.6	99.7	99.5	99.6	100.3	99.7	99.6	99.5	99.6
KTW_L	14.2	13.5	14.5	14.0	14.1	13.9	14.1	13.8	13.8	13.5	13.0
KTW_R	13.5	12.9	13.3	12.1	13.2	12.9	13.1	12.9	13.3	13.0	13.3
KTW_D	1.3	1.6	1.6	2.4	1.7	1.5	1.4	1.6	1.5	1.7	1.7
GS	250	255	246	258	255	258	253	266	256	253	256
Mood	7.6	7.5	7.9	7.2	7.8	7.8	7.7	7.5	7.9	7.9	8.0
Stress	2.2	2.4	1.8	2.1	2.1	2.0	2.1	2.3	2.1	2.2	2.2
Soreness	2.7	2.1	2.2	1.9	2.6	2.2	1.9	1.8	2.0	2.3	2.6
Fatigue	2.4	2.0	2.3	2.4	2.8	2.1	2.0	2.3	2.2	2.4	2.4
Sleep	7.3	7.6	7.2	7.4	7.8	7.9	6.9	7.5	7.6	8.0	7.9
T		637.1	777.4	695.9	994.5	1314.9	1175.8	781.7	1079.9	863.5	1094.9

Table 5.1. Shows the mean group values per week for acute training load (ATL) (AU), chronic training load (CTL) (AU), acute chronic work ratio (ACWR), countermovement jump (CMJ) (cm), body mass (BM) (kg), knee to wall left (KTW_L) (cm), knee to wall right (KTW_R) (cm), knee to wall difference (KTW_D) (cm), groin squeeze (GS) (mmHg), mood, stress, soreness, fatigue, sleep and testosterone (T)(pmol/l) as measured during the course of the study.

	ATL	CTL	ACWR
ATL	1.000	.330**	.729**
CTL	.330**	1.000	-.339**
ACWR	.729**	-.339**	1.000
CMJ	-.082	-.033	-.044
BM	.189*	.313**	-.086
KTW_L	-.084	-.187*	.026
KTW_R	-.018	-.099	.007
KTW_Diff	-.038	-.003	-.024
GS	.024	-.106	.098
Mood	.027	.021	.023
Stress	-.004	.123	-.117
Soreness	.009	.075	-.058
Fatigue	.040	.237**	-.147
Sleep	-.019	.089	-.069
T	-.119	.072	-.198*

Table 5.2. Shows the Spearman's Correlation Coefficient (r) between acute training load (ATL), chronic training load (CTL), acute: chronic work ratio (ACWR), counter movement jump (CMJ), body mass (BM), knee to wall left (KTW_L), knee to wall right (KTW_R), groin squeeze (GS), mood, stress, soreness, fatigue, sleep and testosterone (T) and the training load measures (acute, chronic, acute chronic ratio).

** Denotes a statistical significance ($p < 0.05$)*

***Denotes a statistical significance ($p < 0.01$)*

	CMJ	BW	KTW_L	KTW_R	KTW_Diff	GS
ATL	-.082	.189*	-.084	-.018	-.038	.024
CTL	-.033	.313**	-.187*	-.099	-.003	-.106
ACWR	-.044	-.086	.026	.007	-.024	.098
CMJ	1.000	-.252**	-.092	-.229**	.303**	.335**
BM	-.252**	1.000	.154*	.314**	-.100	-.048
KTW_L	-.092	.154*	1.000	.511**	.056	.180*
KTW_R	-.229**	.314**	.511**	1.000	-.455**	.179*
KTW_Diff	.303**	-.100	.056	-.455**	1.000	.041
GS	.335**	-.048	.180*	.179*	.041	1.000
Mood	-.329**	.047	.271**	.180*	-.013	.002
Stress	.157	.340**	-.069	-.076	-.071	.104
Soreness	.077	.160*	-.056	-.150	-.071	.010
Fatigue	.091	.270**	-.046	-.102	-.006	.020
Sleep	-.336**	.074	.165*	-.023	.040	.048
T	.049	-.113	.012	-.142	.108	.031

Table 5.3. Shows the Spearman's Correlation Coefficient (r) Shows the Spearman's Correlation Coefficient (r) between acute training load (ATL), chronic training load (CTL), acute chronic work ratio (ACWR), counter movement jump (CMJ), body mass (BM), knee to wall left (KTW_L), knee to wall right (KTW_R), groin squeeze (GS), mood, stress, soreness, fatigue, sleep and testosterone (T) and the musculoskeletal measures (countermovement jump, body weight, knee to wall left, knee to wall right, knee to wall difference, groin squeeze).

*Denotes a statistical significance ($p < 0.05$)

**Denotes a statistical significance ($p < 0.01$)

	Mood	Stress	Soreness	Fatigue	Sleep
ATL	.027	-.004	.009	.040	-.019
CTL	.021	.123	.075	.237**	.089
ACWR	.023	-.117	-.058	-.147	-.069
CMJ	-.329**	.157	.077	.091	-.336**
BM	.047	.340**	.160*	.270**	.074
KTW_L	.271**	-.069	-.056	-.046	.165*
KTW_R	.180*	-.076	-.150	-.102	-.023
KTW_Diff	-.013	-.071	-.071	-.006	.040
GS	.002	.104	.010	.020	.048
Mood	1.000	-.239**	-.073	-.235**	.542**
Stress	-.239**	1.000	.461**	.538**	-.040
Soreness	-.073	.461**	1.000	.579**	.013
Fatigue	-.235**	.538**	.579**	1.000	-.115
Sleep	.542**	-.040	.013	-.115	1.000
T	.016	-.044	.033	-.081	.055

_Table 5.4. Shows the Spearman’s Correlation Coefficient (r) Shows the Spearman’s Correlation Coefficient (r) between acute training load (ATL), chronic training load (CTL), acute: chronic work ratio (ACWR), counter movement jump (CMJ), body mass (BM), knee to wall left (KTW_L), knee to wall right (KTW_R), groin squeeze (GS), mood,_

stress, soreness, fatigue, sleep and testosterone (T) and the wellness measures (mood, stress, soreness, fatigue, sleep).

**Denotes a statistical significance ($p < 0.05$)*

***Denotes a statistical significance ($p < 0.01$)*

Discussion

This study observed that there are relationships between the different monitoring tools used by sports medicine and sport science staff. The need for the use of a holistic approach to training load monitoring is clear from the data gathered here; suggesting the use of combining measures of workload with perceptual well-being scores, (Herbert et al*.,* 2015). Mood had a moderate, negative correlation (r = - 0.329) with counter movement jump height. Mood shows a consistent dose-response relationship with training stress, (Bouget et al*.,* 2000), and has been related to performance and training recovery, (Shearer et al*.,* 2015). The precise mechanisms that link the mood response to high-intensity exercise have not been examined extensively or determined in the current research, but these changes have been suggested to be related to both hormonal response and other perceptual factors such as reflections on personal performance, (Berger and Motl, 2000).

The moderate negative correlation between mood and countermovement jump (r = - 0.329) indicated that there was an inverse relationship between a participant's selfperception of mood state and neuromuscular performance. This is in keeping with findings by Shearer et al*.,* (2015), which demonstrated a similar inverse relationship between mood and countermovement jump (*r* = -0.340). There are several studies which have examined the relationship between mood and power output or physical performance, but the majority of these studies examine them concurrently with an intervention such as carbohydrate limiting diets, (Killer et al*.,* 2017), or as a result of rugby union match play, (West et al*.,* 2014). Killer et al*.,* (2017)*,* identified a decreased power output concurrent with a decreased mood state when well-trained cyclists trained in a carbohydrate restricted state, although the reduction in both is linked more to the reduction in glycogen as a result of the intervention. West et al*.,* (2014), observed that there were decreases in mood state after a rugby union match as well as decreases in jump height, however, there was no relationship between the decreases in both, (p = 0.133). It was also observed that mood returned to pre-match levels quicker than jump height, power output or hormonal markers with mood returning to baseline by 36 hours while the other measures did not return to baseline for 60 hours. The relationship between mood and all of these markers was also insignificant, (p > 0.05). The lack of a significant relationship between mood and jump height may be due to muscular damage or fatigue as a result of collisions and match play in rugby union.

As previously stated, Shearer et al*.,* (2014), displayed a similar inverse relationship between mood and power output (*r* = -0.340). Again, however, the study by Shearer et al*.,* was examining the relationships in response to rugby union match play. There is little research examining a relationship between mood and neuromuscular performance over a prolonged time course. This study finds that the relationship between mood and countermovement jump height indicates measurement of self-perceived mood may be a simple, non-invasive, cost effective tool to measure readiness to train and perform over a season or part of a competitive season. As this study observes mood and jump performance over a longer time period (11 weeks) this would suggest that mood and mood disruptions may be indicative of readiness to perform. Around periods that are likely to cause mood disruptions such as exams for collegiate athletes training may need to be tailored to reflect this and efforts made to attenuate negative impacts.

There was a large, positive relationship between sleep and mood (*r* = 0.542). Previous research has indicated that decreases in quality of sleep will result in negative changes in mood state as reported by participants, (Polman et al*.,* 2007. Scott et al*.,* 2006), which is in keeping with the findings of this study. However, this study disagrees with previous studies in relation to sleep and neuromuscular performance finding that sleep quality as self-reported by the participants had a moderate negative correlation (*r* = -0.336) with countermovement jump height. The effect of sleep quality on single or limited bouts of maximal exercise, such as a countermovement jump have been equivocal, (Fullagar et al*.,* 2015), although in a meta-analysis of effect of sleep on performance, Thun et al*.,* (2015), stated that jump performance can be affected by sleep deprivation. 64 hours of sleep deprivation resulted in a decrease in vertical jump height. 64 hours of sleep deprivation is unlikely in most normal and athletic populations. Sleep restriction (2.5 to 3 hours per night) which is intuitively more likely in normal circumstances has shown no effect on broad jump performance according to the authors review of the literature. Generally, it has been observed that low sleep quality (through sleep deprivation or restriction) has a negative impact on neuromuscular performance, it should follow that good sleep quality would have a direct relationship with performance. This is the inverse of the findings here. This could be due to cumulative fatigue as a result of the period of international competition which could have decreased jump performance as opposed to changes in sleep quality. Johnston et al*.,* (2013), found that there were reductions in lower limb neuromuscular performance as measured by countermovement jump during periods of competition.

Similar to the findings in relation to mood, the main body of research examines sleep in shortened time periods or under experimental conditions, such as sleep deprivation. This study examines the relationship between sleep and other athlete monitoring measures over a longer time course (11 weeks of an international competition). Therefore, the relationship between countermovement jump performance and sleep quality over the competition may be affected by the duration of the study. Some of the findings of these studies have been confounded by small sample sizes, having less than 10 participants. While the sample size in this study is small, (n = 16), this must be balanced against using elite participants making the data inference to this population more meaningful, (Shearer et al*.,* 2015).

There was a moderate positive correlation (*r* = 0.335) between counter movement jump height and the groin squeeze test. Twist and Highton, (2013), have promoted the use of jump measures as a monitor of fatigue and neuromuscular function in team sport activities. The use of adductor strength and the groin squeeze as a diagnostic tool for the onset of hip and groin pathologies is well documented, (Delahunt et al*.,* 2011), however, there appears to be no research into its use to assess neuromuscular performance or fatigue. The correlation demonstrated here could lend credence to its use as a measure of neuromuscular fatigue and readiness to perform. Sphygmomanometers are relatively inexpensive so may be an easily self-administered monitor for athletes that can indicate neuromuscular state or readiness to perform.

Hand grip strength has been used to measure neuromuscular and endocrine responses to exercise in previous research, (Crewther et al*.,* 2017). Hand grip strength is measured using maximum voluntary contraction similar to the adductor squeeze test and could be indicative of neural fatigue or readiness to perform. As the joint angle used in this study (45^{o}) has been shown by electyromyography to have the greatest muscular activation of any position when performing the adductor squeeze test, (Delahunt et al*.,* 2011), this would support its efficacy as a measure of neuromuscular performance and fatigue and may explain the correlation with counter movement jump height.

The large positive correlations between mood and sleep, (*r* = 0.542), is in keeping with other studies. Lastella et al*.,* (2014), stated that disruption of sleep can negatively affect mood and can lead to increases in fatigue, confusion and tension. Therefore, it can follow that increased sleep quality will lead to improved mood state. Carlson and Garland, (2005), determined that there is a significant relationship between self-reported stress and self-reported fatigue, (*r* = 0.53, p < 0.001). This is in line with what was observed in this study with a correlation of *r* = 0.54, (p < 0.01) between stress and fatigue. Although it was not seen here this study identified a correlation between sleep quality and improvements in fatigue (*r* = 0.53, p < 0.001), improvements in mood, (*r* = 0.46, p < 0.001), and improvements in stress (*r* = 0.38, p < 0.001). The study by Carlson and Garland was not using an athletic population and although the evidence thus far into athlete sleep habits and quality has been equivocal, (Gupta et al*.,* 2016), there is a suggestion that athletes may have poorer sleep quality and duration. During this study participants reported that their average rating of sleep quality was 7.6 (on a Likert 1-10 scale, worst to best) with a standard deviation of ± 0.4. The generally high sleep quality and small variation may result in the lack of a correlation here between the measures of soreness, fatigue and stress.

Subjective measurements of fatigue have been shown to be sensitive to changes in training stress, (Coutts et al*.,* 2007), and have been used to assess recovery in rugby players, (Twist et al*.,* 2012). Changes in self-reported mental fatigue have been linked to changes in perception of effort, forcing athletes to down regulate their exercise capacity, (Marcora et al*.,* 2009). Several studies have investigated self-reported wellness measures over longer time frames, from 2 weeks of a preseason camp, (Bucheit et al*.,* 2012), to part of a full season over 183 days, (Gastin et al*.,* 2013), to two full competitive seasons, (Brink et al*.,* 2012). Bucheit et al*.,* observed that there was a correlation between soreness and heart rate variability, (*r* = -0.41 - -0.63). Heart rate variability, submaximal exercise heart rate and training load correlated to self-reported wellness with correlations ranging from moderate to very large. There were, however, no correlations seen between any of the measures and testosterone which was examined during this study. Wellness measures were seen to be a valid and reliable measure of physiological response during this time frame of training. Similar to this study the wellness measures were fatigue, sleep quality, soreness, mood and stress, which were all rated on a Likert scale ranging from worst to best. The study by Gastin et al*.,* which took place over a phase of the season similar to this study (26 and 11 weeks respectively) demonstrated that subjective ratings of psychological wellness were sensitive to weekly training load manipulations (p < 0.001) and to individual characteristics for example muscle strain, (p < 0.001).

This study demonstrated the relationship between perceptions of wellness (mood and sleep) and neuromuscular performance (countermovement jump height) which would suggest they are valid indicators of physiological response to training and exercise. There were correlations observed within the measures of wellness with stress, soreness and fatigue demonstrating moderate to strong correlations (*r* = 0.461 – 0.579) and sleep and mood having a strong correlation (*r* = 0.542).

There was, however, no correlation observed between testosterone and any of the other measures used in this study. This is in keeping with findings by West et al*.,* (2014), who stated that there was no relationship between testosterone changes after rugby union match play and measures of mood or jump height ($p > 0.05$). There are few studies that examine the relationship between perception of wellness scores and endocrine responses to training, (Maso et al*.,* 2004). Maso et al's*.,* study identified that there was a moderate to large correlation between testosterone and psychometric measures of overtraining (r = 0.43 – 0.6). Both of these studies are ambiguous on the reasons for why the correlation may or may not exist. Twist et al*.,* (2013), stated that due to the poor temporal relationships with fatigue and the multifaceted components of fatigue that a single biochemical, hormonal or immunological measure cannot account for it, which this study would appear to corroborate.

What is more well established is the correlation between testosterone and neuromuscular performance, (Cardinale and Stone, 2006). Their study identified that there was a significant positive correlation between serum testosterone and vertical jump height, ($r = 0.61$, $p < 0.001$), this was only examined in a single testing bout and not taken over a longer time course. This study observed a trivial correlation between testosterone and countermovement jump height ($r = 0.049$, $p > 0.05$). The current study, however, was examining the relationship longitudinally and therefore may be confounded by outside factors, such as collisions involved in rugby union training.

There was small to trivial correlations between the training load measures; acute, chronic and acute to chronic training load ratio, and any of the other measures of training load (*r* < 0.3 for all measures). This may be due to several confounding factors; part of the total training load each week is attributable to resistance training sessions. While sRPE has been shown to be valid for measuring training load in field based sessions, (Buchheit et al*.,* 2013), the reliability of sRPE when used to quantify training load in resistance has shown equivocal evidence in research with suggestions being that it cannot account for the physiological stress of resistance training, (Borresen and Lambert, 2009; Day et al., 2004; Sweet et al*.,* 2004.). The study by Sweet et al*.,* (2004), showed that sRPE can vary significantly depending on the muscle group used in a given training session, due to differences in muscle mass, range of motion and number of joints used in the movement.

In the current study training load for resistance training sessions was calculated by multiplying sRPE by the duration of the session but it has been suggested by Day et al*.,* (2004), that it would be more beneficial in a resistance training session to multiply number of reps by sRPE to get the training load using that method. This may have shown a better correlation with endocrine or perception of wellness markers as it would better account for the training stress as a result of resistance training. However, the 2013 study by Buchheit et al*.,* examined training load in correlation with hormonal measures and wellness measures over a 2-week preseason camp. The training for this preseason training camp consisted of field as well as resistance training sessions and there was observed a significant effect of variance in training load and all wellness measures (p<0.001). The measures in this study were taken daily as opposed to weekly in this study so perhaps they need to be taken at regular time points to be sensitive to changes in training load.

Conclusions

The present study demonstrates that there is a relationship between different measures of training load although, not all measures demonstrated a correlation in accordance with previous research. The correlations between perceptions of wellness monitoring and neuromuscular response observed here are in keeping with previous research. This increased perception of fatigue or stress will cause a down regulation in an athlete's capacity of exercise and may indicate a reduced capacity for sports performance as demonstrated here by the negative correlations between mood, sleep quality and counter movement jump performance. The correlations between countermovement jump performance and groin squeeze test show that decreases in neural drive can be measured using various methods. This is useful as depending on the resources or constraints in a given sporting environment there are multiple methods to monitor the same response.

The poor correlations with training load as measured by the sRPE method is in contrast to previous research. A confounding factor of this study may be that the time points at which the wellness measures were taken were not frequent enough so as to be sensitive to changes in training load. It is suggested that these monitors be taken more frequently, daily if possible and at a consistent time of the day.

The research into endocrine response to training load has been equivocal thus far and this study has identified no relationship between endocrine response and measures of training load. It has been suggested previously by Twist et al*.,* (2012), that the use of biomarkers may be difficult in training load monitoring as no biomarker can account for the milieu of physiological stress of multi-faceted sports like rugby union. Consideration should be given to other biomarkers or the use of more frequent biomarker measurements.

This study suggests that a holistic approach to training load monitoring is the most effective way to account for all the various stressors that are incurred during rugby union training. No one measure can fully account for all components of training load. The measures used should be considered dependant on the resource available to the team or sport science practitioner. The time course or frequency is also of important consideration when deciding on a monitoring battery. According to Gabbett et al*.,* (2017), an athlete monitoring program should marry measures of internal training load and external training load, combine measures of workload with perceptions of wellness, and combine a measure of readiness to perform with measures of training load. This study determined that there are relationships between measures of readiness to perform (countermovement jump, groin squeeze and sleep quality, mood). The relationship between measures of training load and the other responses are equivocal. More research on the temporal course and interaction of the different measures will be needed.

While this study does suggest that a holistic approach to training load monitoring should be taken; whereby internal and external measures of training load response are taken as well as objective and subjective measures, it also suggests that a stream lining of a monitoring program could be useful. If all psychocomportemental measures of training load response do not have the same relationship with performance, then it is not essential to monitor them all. As self-reported mood and sleep have an inverse relationship with neuromuscular performance then these two metrics should be the focus of a future monitoring program. As there are strong correlations between sleep and mood, and between fatigue and soreness then it may not be essential to track all of these metrics to further streamline the monitoring process.

As there is a moderate positive relationship between groin squeeze and counter movement jump then it might be of value to less well-resourced clubs and teams to consider groin squeeze as a measure of neuromuscular performance. Resources may not just be financial but human resources such as time to monitor data, (Halson, 2014), so therefore a reduction of data that needs to be monitored may be beneficial. This may also be of value as it will remove a technical component to the CMJ which may affect results across different time points. This study suggests that where there are relationships between the metrics that there may be scope for a streamlining. Furthermore, the less time consuming and extensive a battery of monitoring tools is, the greater chance of athlete compliance and athlete compliance is essential for meaningful and consistent data collection, (Halson, 2014).

The third hypothesis was rejected as there was a relationship between objective and subjective measures of training load. This study demonstrated that there was a moderate positive correlation between stress and soreness (r = 0.461), and groin squeeze and countermovement jump (r = 0.335). There were moderate negative correlations between countermovement jump and mood (r = -0.329), and between countermovement jump and sleep (r = -0.336). There were large positive correlations between sleep and mood (r = 0.542), between stress and fatigue (r = 0.538) and between fatigue and soreness (r = 0.579). This study supports the use of a holistic approach to training load monitoring in athletes. There is a relationship between the measures of training load, which indicates that regardless of the facilities and resources available to a team or organisation there are still effective methods whereby the training response may be monitored and manipulated. This may help lead to improved performance and a reduction in injury risk to athletes.

There were several limitations to this study. The training load measures were taken daily, whereas all other measures were only taken weekly. This was due to practical constraints. Future longitudinal studies should consider using more frequent measures of training load response to give a more accurate reflection of the relationship between training load monitors. The small sample size (n = 16) limits the power of this study but the inference to an elite athletic population makes it a worthwhile study.

Summary

The aim of this study was to examine the different measures of training load monitoring used in rugby union and their correlation with each other. The present study also aimed to determine whether individual or arbitrary definitions of high speed running metres using GPS technology correlate to physiological measures of training load. This study is the first study to use biomarkers of training load to determine the definitions of high speed running metres. This study was conducted by using GPS technology, musculoskeletal reviews, perception of wellness monitoring and session rate of perceived exertion data from elite U20 Rugby Union players during different phases of a season.

Study 1 examined the reliability and validity of GPS units to measure rugby union specific game demands. This was achieved by comparing interunit measures of distance, velocity and acceleration in conjunction with known measures of given metrics. This study observed that distance (m), max velocity (ms^{-1}) and distance covered at a velocity of $>2ms^{-1}$ had a strong ICC between units (>0.9), however distance covered showed a significant difference to the predicted distance covered ($p<0.05$). Max velocity showed no significant difference ($p>0.05$) as did number of tackles. However, number of tackles had a lower but still large ICC (0.665). The number of accelerations in different bands showed a very large ICC (>0.8), however, the CV was poor (29-68%). The CV was good for distance and velocity. This study concluded that GPS units sampling at 10 Hz are reliable and valid for reporting distance

and velocity related metrics, however, may not be as reliable and valid for acceleration and tackle related metrics.

Study 2 examined the correlation between internal measures of training load with individual and arbitrary definitions of high speed running metres. This was achieved by comparing distances covered above given velocity thresholds with session rate of perceived exertion and biomarkers of training load. This study observed that high speed running metres as defined by 60% of VMax and MAS had a large, positive correlation with sRPE derived training load ($r = 0.518$ and 0.574, $p < 0.01$) compared to the arbitrary measure ($r = 0.431$, $p < 0.01$) which had a moderate positive correlation. All other correlations were moderate or trivial. This study concluded that individual definitions of high speed running metres having a stronger relationship with internal training load response as observed by its correlation with training load.

Study 3 examined the correlation between measures of training load monitoring during an 11-week period of international competition. This was achieved by comparing the different session rate of perceived exertion for the full week and groin squeeze, countermovement jump, knee to wall, testosterone, cortisol, their ratio, sleep quality, mood, fatigue, stress, and soreness. This study observed that there were moderate, positive correlations between stress and body weight, stress and soreness, groin squeeze and countermovement jump and knee to wall difference and countermovement jump. There were moderate, negative correlations between countermovement jump and mood and sleep. There are strong, positive correlations between sleep and mood, stress and fatigue and fatigue and soreness. All other correlations were trivial. This study concluded that perception of wellness measures are sensitive to physiological, neuromuscular or musculoskeletal responses to training load. This correlation may be indicative of capacity to perform, likelihood to get injured or recovery from a training or competition bout. More cost-effective measures such as groin squeeze may be able to indicate capacity for neuromuscular performance.

Practical Applications

There are many effective methods for training load monitoring that may be employed by strength and conditioning and sport science practitioners working with elite athletic populations. Global Positioning System technology is a valid and reliable method for quantifying distance and velocity-based training metrics and may be used to describe rugby union demands. It may also be used to determine the external training load of team sport players and athletes. This study is the only study found in an extensive literature review that uses units measuring concurrently to determine reliability of units. This lends credence to the interunit reliability of GPS units to describe rugby union related metrics.

This study advocates the use of individual thresholds of high speed running metres when using GPS technology to allow for the individual differences in capacity between individual athletes. This is the first study that uses a physiological basis for the prescription of high speed running metre thresholds while aiming to correlate them to training load response. This novel approach lends credence to the used of individual and physiologically based definitions for HSRM.

This study also demonstrates that there are correlations between the different measures of training load monitoring. A holistic approach to training load monitoring is recommended so as to determine the athlete response to training, therefore employing different methods of training load monitoring methods to cover the multitude of training load stressors. This will allow strength and conditioning coaches and sport science professionals to determine readiness to perform and how an individual athlete is tolerating the training load. This study also suggests that through the close relationship between some of the measures of training load employed that there could be a streamlining of monitoring tools employed. This would aim to increase athlete compliance with monitoring tools and make data management handling more efficient for clubs or teams with limited human resources and man hours available.

Future Research

Studies into the reliability and validity of GPS unit should be carried out using live game situations rather than simulated team circuits so as to further advance the use of GPS technology in team sport. With continuing advances in GPS technology, research to validate the improving technology needs to be continuously performed.

Future research into high speed running metres in team sport should consider using individual thresholds of high speed running metres. The thresholds used in rugby union need to be further considered to further validity for the sport. Due to the anaerobic nature of the sport an anaerobic measure of metabolic stress should be considered. Future research should also consider using pre and post training measures of the given bio markers.

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Appendices

Appendix A Study 1 Consent Form

CONSENT TO PARTICIPATE IN RESEARCH

Reliability and Validity of GPS Units

You are being invited to participate in a research study which aims to compare data gathered from GPS units to determine their reliability. This study is being conducted by Michael Lawlor (researcher), Declan Browne and Paula Rankin (research supervisors) from the Department of Science and Health at Institute of Technology Carlow (herein referred to as IT Carlow). This study is being completed as part of Masters of Science by research.

Your participation in this study is entirely voluntary. Please read the information below and ask questions about anything you do not understand, before deciding whether or not to participate.

You have been asked to participate in this study as you are a collegiate level Rugby Union player.

PURPOSE OF THE STUDY

The purpose of this study is to determine if GPS units measure reliability the metrics which they purport to measure.

PROCEDURES

Subjects will be required to complete a team game with contact simulated circuit 15 times wearing a GPS unit.

Prior to this they will complete a standardized warm up which will include familiarization laps of the circuit. They will the complete the circuit which will include walking, striding, sprinting and collisions.

POTENTIAL RISKS AND DISCOMFORTS

The risk posed to the subject will be minimal as they will not be exposed to any activities they would not be familiar and comfortable with as collegiate level Rugby Union players.

POTENTIAL BENEFITS TO SUBJECTS AND/ OR TO SOCIETY

Participation in this study will have no direct benefits to the subject, however, the aim of this study is to determine the viability of GPS units as training aid in Rugby Union.

CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Confidentiality will be maintained by means of keeping all data in a secured location with restricted access in the case of manual information and on a password protected hard drive in the case of electronic data.

In case of an emergency, injury, or illness that occurs during this study, I hereby authorize the release of any and all health information to allow for medical care and treatment of my condition.

PARTICIPATION AND WITHDRAWAL

You can choose whether or not to be in this study. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind or penalty.

The investigator may withdraw you from this research if circumstances arise which warrant doing so.

IDENTIFICATION OF INVESTIGATORS

If you have any questions about the study, please contact

Michael Lawlor
Institute of Technology, Carlow
Kilkenny Road, Carlow
michael.lawlor@itcarlow.ie
(085) 777 4568

RIGHTS OF RESEARCH SUBJECTS

IT Carlow's Research Ethics Committee has reviewed and approved my request to conduct this project. If you have any concerns about your rights in this study, please contact the Chair of the Research Ethics Committee

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

____

Printed Name of Subject

Appendix B Study 2 and 3 Consent Form

CONSENT TO PARTICIPATE IN RESEARCH

The Comparison of Objective to Subjective Measures of Training Load in Elite Age Grade Rugby Union

You are being invited to participate in a research study which aims to compare different measures of training load in elite age grade rugby union and their effect on performance. This study is being conducted by Michael Lawlor (researcher), Paula Rankin and Declan Browne (research supervisors) from the Department of Science and Health at Institute of Technology Carlow (herein referred to as IT Carlow). This study is being completed as part of a Masters of Science by research.

Your participation in this study is entirely voluntary. Please read the information below and ask questions about anything you do not understand, before deciding whether or not to participate.

You have been asked to participate in this study as you are a member of the Leinster Rugby under 20s squad and as such are considered an elite age grade Rugby Union player.

PURPOSE OF THE STUDY

The purpose of this study is to determine if there is a correlation between different methods of monitoring training load in elite age grade Rugby Union. Furthermore, to determine if there is a correlation between these measures and performance and injury/illness rates in players.

PROCEDURES

During the course of your normal training and match participation as part of the Leinster Rugby under 20s squad you will be monitored using several methods; these include Global Positioning System (GPS) units, session rate of perceived exertion (SRPE), neural measures (counter movement jump, groin squeeze) and hormonal markers (salivary testosterone to cortisol ratios).

Prior to pitch based training sessions you will be fitted with a GPS unit worn under your training top in a bespoke vest. 30 minutes post training you will be asked for your session RPE and asked to give a non-invasive salivary sample.

Prior to gym sessions you will be asked to perform 3 counter movement jumps and a groin squeeze test.

If you volunteer to participate in this study, you will be asked to participate in the usual match and training schedule as normal and consent to wearing the GPS units throughout as well providing salivary cortisol samples post training/

matches in conjunction with RPE. Prior to each gym session you will be asked to perform three counter movement jumps and a groin squeeze test.

The purpose of this study is to determine if there is a correlation between subjective (RPE) and objective (GPS, Neural response and hormonal response) measures of training load tolerance and their effect on performance in age grade Rugby Union players.

POTENTIAL RISKS AND DISCOMFORTS

As this study is observational in nature subjects will not be exposed to conditions that may pose potential risks or additional discomfort above and beyond the usual demand of participation in a collision sport like Rugby Union.

IT Carlow does not provide any medical, hospitalization or other insurance for participants in this research study, nor will IT Carlow provide any medical treatment or compensation for any injury sustained as a result of participation in this research study, except as required by law.

POTENTIAL BENEFITS TO SUBJECTS AND/ OR TO SOCIETY

Participation in this study will have no direct benefits to the subject, however, the aim of this study is to have a better understanding of training load monitoring in age grade rugby union players and therefore inform best practice for training load monitoring and prescription in this athletic population.

CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Confidentiality will be maintained by means of keeping all data in a secured location with restricted access in the case of manual information and on a password protected hard drive in the case of electronic data.

In case of an emergency, injury, or illness that occurs during this study, I hereby authorize the release of any and all health information to allow for medical care and treatment of my condition.

PARTICIPATION AND WITHDRAWAL

You can choose whether or not to be in this study. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind or penalty.

The investigator may withdraw you from this research if circumstances arise which warrant doing so.

IDENTIFICATION OF INVESTIGATORS

If you have any questions about the study, please contact

Michael Lawlor
Institute of Technology, Carlow
Kilkenny Road, Carlow
michael.lawlor@itcarlow.ie
(085) 777 4568

RIGHTS OF RESEARCH SUBJECTS

IT Carlow's Research Ethics Committee has reviewed and approved my request to conduct this project. If you have any concerns about your rights in this study, please contact the Chair of the Research Ethics Committee

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

____

Printed Name of Subject

____

Signature of Subject Date

____

Signature of Witness Date

Appendix C GPS Data for Study 1

				s/ v band (ms-1)				Efforts/ a band (ms^2)					
		s	Max v	0-2	2-4	4-6	>6	0-1	1-2	2-4	4+	Sum	Tackles
Subject	Unit	*m*	*ms-1*	*m*	*m*	*m*	*m*	*n*	*n*	*n*	*n*	*n*	*n*
1	**1**	2123	6.5	761	698	602	62	13	5	2	14	34	16
	2	2228	6.6	942	741	462	83	9	9	7	11	36	19
	3	2204	6.7	915	779	431	79	10	10	4	12	36	20
	4	2213	6.8	889	670	565	89	13	8	4	11	36	18
	Mean	2192	6.65	876.75	722	515	78.25	11.25	8	4.25	12	35.5	18.25
	SD	40.7	0.1	69.4	41.5	70.6	10.0	1.8	1.9	1.8	1.2	0.9	1.5
2	**5**	2016	6.4	679	737	517	83	10	9	5	11	35	16
	6	2061	6.5	778	809	442	32	13	7	6	12	38	13
	7	2104	6.6	852	801	383	68	10	7	8	13	38	1
	8	2067	6.7	766	772	420	109	14	8	4	14	40	13
	Mean	2062	6.55	768.75	779.75	440.5	73	11.75	7.75	5.75	12.5	37.75	10.75
	SD	31.2	0.1	61.4	28.3	48.9	27.8	1.8	0.8	1.5	1.1	1.8	5.8
3	**9**	2194	5.8	874	910	410	0	18	11	9	7	45	20
	10	2168	5.9	956	859	353	0	22	11	10	9	52	16
	11	2065	5.9	865	867	333	0	20	17	18	7	62	16
	12	2046	6.0	828	849	367	2	14	19	16	6	55	16
	Mean	2118.3	5.9	880.75	871.25	365.75	0.5	18.5	14.5	13.25	7.25	53.5	17
	SD	63.8	0.1	46.7	23.3	28.3	0.9	3.0	3.6	3.8	1.1	6.1	1.7
4	**13**	2035	6.8	688	647	622	78	11	11	1	14	37	20
	14	2016	6.8	727	656	544	89	14	8	4	11	37	17
	15	2073	7.3	810	624	521	118	10	11	4	11	36	18
	16	2039	7.2	766	609	561	103	13	9	6	10	38	11
	Mean	2040.8	7.025	747.75	634	562	97	12	9.75	3.75	11.5	37	16.5
	SD	20.5	0.2	45.3	18.6	37.4	15.0	1.6	1.3	1.8	1.5	0.7	3.4
5	**17**	2006	5.9	730	977	297	2	13	22	4	10	49	11
	18	1924	5.9	776	888	158	2	21	16	15	5	57	13
	19	2006	5.8	853	878	273	2	22	16	12	10	60	13
	20	1957	6.0	837	860	257	3	18	14	20	8	60	13
	Mean	1973.3	5.9	799	900.75	246.25	2.25	18.5	17	12.75	8.25	56.5	12.5
	SD	34.8	0.1	49.1	45.2	52.9	0.4	3.5	3.0	5.8	2.0	4.5	0.9

Appendix D Timing Gate Data for Study 1

Subject 1																		
Timing Gates				Speed (initial)			Speed (final)			Acceleration			Time			Distance		
s				ms-1			ms-1			ms^2			s			m		
Start Time	5m	10m	20m	u5	u10	u20	v5	v10	v20	a5	a10	a20	t5	t10	t20	s5	s10	s20
1142	1.08			0	4.63		4.63			4.63	-0.34		1.08			5	5	10
1144	1.07	1.82	3.60	0	4.67	6.67	4.67	6.67	5.62	4.67	0.44	1.87	1.07	0.75	1.78	5	5	10
1146	1.09	1.89	3.69	0	4.59	6.25	4.59	6.25	5.56	4.59	0.52	2.08	1.09	0.80	1.80	5	5	10
1147	1.10	1.90	3.78	0	4.55	6.25	4.55	6.25	5.32	4.55	0.57	1.99	1.10	0.80	1.88	5	5	10
149	1.05	1.82	3.60	0	4.76	6.49	4.76	6.49	5.62	4.76	0.31	1.97	1.05	0.77	1.78	5	5	10
1151	1.08	1.88	3.65	0	4.63	6.25	4.63	6.25	5.65	4.63	0.46	2.12	1.08	0.80	1.77	5	5	10
1152	1.08	1.88	3.72	0	4.63	6.25	4.63	6.25	5.43	4.63	0.46	2.04	1.08	0.80	1.84	5	5	10
1154	1.05	1.85	3.80	0	4.76	6.25	4.76	6.25	5.13	4.76	0.30	1.92	1.05	0.80	1.95	5	5	10
1156	1.13	1.95	3.87	0	4.42	6.10	4.42	6.10	5.21	4.42	0.70	2.03	1.13	0.82	1.92	5	5	10
1158	1.08	1.87	3.64	0	4.63	6.33	4.63	6.33	5.65	4.63	0.47	2.07	1.08	0.79	1.77	5	5	10
1159	1.22	2.17	4.61	0	4.10	5.26	4.10	5.26	4.10	4.10	0.95	1.94	1.22	0.95	2.44	5	5	10
1202	1.06	1.84	3.71	0	4.72	6.41	4.72	6.41	5.35	4.72	0.36	1.92	1.06	0.78	1.87	5	5	10
1204	1.15	2.00	3.98	0	4.35	5.88	4.35	5.88	5.05	4.35	0.77	2.08	1.15	0.85	1.98	5	5	10
1205	1.12	1.91	3.79	0	4.46	6.33	4.46	6.33	5.32	4.46	0.68	1.95	1.12	0.79	1.88	5	5	10
1207	1.12	1.95	3.83	0	4.46	6.02	4.46	6.02	5.32	4.46	0.65	2.11	1.12	0.83	1.88	5	5	10

Subject 2																		
Timing Gates				Speed (initial)			Speed (final)			Acceleration			Time			Distance		
s				ms-1			ms-1			ms^2			s			m		
Start Time	5m (s)	10m (s)	20m (s)	u5	u10	u20	v5	v10	v20	a5	a10	a20	t5	t10	t20	s5	s10	s20
1143	1.07	1.90	3.49	0	4.67	6.02	4.67	6.02	6.29	4.67	0.39	2.50	1.07	0.83	1.59	5	5	10
1144	0.96	1.79	3.54	0	5.21	6.02	5.21	6.02	5.71	5.21	-0.25	2.27	0.96	0.83	1.75	5	5	10
1146	1.01	1.82	3.52	0	4.95	6.17	4.95	6.17	5.88	4.95	0.06	2.25	1.01	0.81	1.70	5	5	10
148	1.07	1.85	3.55	0	4.67	6.41	4.67	6.41	5.88	4.67	0.42	2.11	1.07	0.78	1.70	5	5	10
149	1.08	1.88	3.67	0	4.63	6.25	4.63	6.25	5.59	4.63	0.46	2.09	1.08	0.80	1.79	5	5	10
1151	1.04	1.86	3.58	0	4.81	6.10	4.81	6.10	5.81	4.81	0.23	2.27	1.04	0.82	1.72	5	5	10
1153	1.03	1.86	3.56	0	4.85	6.02	4.85	6.02	5.88	4.85	0.18	2.34	1.03	0.83	1.70	5	5	10
1154	0.94	1.75	3.50	0	5.32	6.17	5.32	6.17	5.71	5.32	-0.39	2.19	0.94	0.81	1.75	5	5	10
1156	1.03	1.80	3.47	0	4.85	6.49	4.85	6.49	5.99	4.85	0.19	2.10	1.03	0.77	1.67	5	5	10
1158	0.97	1.73	3.42	0	5.15	6.58	5.15	6.58	5.92	5.15	-0.20	2.02	0.97	0.76	1.69	5	5	10
1200	1.08	1.88	3.65	0	4.63	6.25	4.63	6.25	5.65	4.63	0.46	2.12	1.08	0.80	1.77	5	5	10
1202	1.01	1.85	3.58	0	4.95	5.95	4.95	5.95	5.78	4.95	0.06	2.34	1.01	0.84	1.73	5	5	10
1204	1.03	1.86	3.71	0	4.85	6.02	4.85	6.02	5.41	4.85	0.18	2.15	1.03	0.83	1.85	5	5	10
1206	0.92	1.71	3.45	0	5.43	6.33	5.43	6.33	5.75	5.43	-0.55	2.11	0.92	0.79	1.74	5	5	10
1207	1.06	1.91	3.70	0	4.72	5.88	4.72	5.88	5.59	4.72	0.33	2.30	1.06	0.85	1.79	5	5	10

Subject 3																		
Timing Gates				Speed (initial)			Speed (final)			Acceleration			Time			Distance		
s				ms-1			ms-1			ms^2			s			m		
Start Time	5m (s)	10m (s)	20m (s)	u5	u10	u20	v5	v10	v20	a5	a10	a20	t5	t10	t20	s5	s10	s20
1143	1.11	1.99	3.85	0	4.50	5.68	4.50	5.68	5.38	4.50	0.56	2.32	1.11	0.88	1.86	5	5	10
1145	1.07	1.93	3.86	0	4.67	5.81	4.67	5.81	5.18	4.67	0.38	2.17	1.07	0.86	1.93	5	5	10
1146	1.09	1.94	3.85	0	4.59	5.88	4.59	5.88	5.24	4.59	0.49	2.16	1.09	0.85	1.91	5	5	10
1148	1.11	1.98	3.99	0	4.50	5.75	4.50	5.75	4.98	4.50	0.57	2.12	1.11	0.87	2.01	5	5	10
1150	1.18	2.07	4.04	0	4.24	5.62	4.24	5.62	5.08	4.24	0.86	2.22	1.18	0.89	1.97	5	5	10
1151	1.18	2.07	3.98	0	4.24	5.62	4.24	5.62	5.24	4.24	0.86	2.29	1.18	0.89	1.91	5	5	10
1153	1.10	1.99	4.09	0	4.55	5.62	4.55	5.62	4.76	4.55	0.51	2.09	1.10	0.89	2.10	5	5	10
1155	1.14	2.07	4.22	0	4.39	5.38	4.39	5.38	4.65	4.39	0.66	2.15	1.14	0.93	2.15	5	5	10
1157	1.09	1.97	3.95	0	4.59	5.68	4.59	5.68	5.05	4.59	0.47	2.18	1.09	0.88	1.98	5	5	10
1158	1.08	1.99	4.08	0	4.63	5.49	4.63	5.49	4.78	4.63	0.41	2.16	1.08	0.91	2.09	5	5	10
1201	1.22	2.11	4.27	0	4.10	5.62	4.10	5.62	4.63	4.10	1.01	2.03	1.22	0.89	2.16	5	5	10
1202	1.20	2.18	4.48	0	4.17	5.10	4.17	5.10	4.35	4.17	0.85	2.13	1.20	0.98	2.30	5	5	10
1204	1.08	2.03	4.27	0	4.63	5.26	4.63	5.26	4.46	4.63	0.39	2.11	1.08	0.95	2.24	5	5	10
1206	1.16	2.10	4.20	0	4.31	5.32	4.31	5.32	4.76	4.31	0.73	2.23	1.16	0.94	2.10	5	5	10
1208	1.11	2.01	4.01	0	4.50	5.56	4.50	5.56	5.00	4.50	0.55	2.22	1.11	0.90	2.00	5	5	10

Subject 4																		
Timing Gates				Speed (initial)			Speed (final)			Acceleration			Time			Distance		
s				ms-1			ms-1			ms^2			s			m		
Start Time	5m (s)	10m (s)	20m (s)	u5	u10	u20	v5	v10	v20	a5	a10	a20	t5	t10	t20	s5	s10	s20
1144	1.04	1.81	3.53	0	4.81	6.49	4.81	6.49	5.81	4.81	0.25	2.04	1.04	0.77	1.72	5	5	10
1145	1.14	1.91	3.77	0	4.39	6.49	4.39	6.49	5.38	4.39	0.80	1.89	1.14	0.77	1.86	5	5	10
1147	1.12	1.90	3.91	0	4.46	6.41	4.46	6.41	4.98	4.46	0.69	1.79	1.12	0.78	2.01	5	5	10
1148	1.13	1.92	3.82	0	4.42	6.33	4.42	6.33	5.26	4.42	0.73	1.93	1.13	0.79	1.90	5	5	10
1150	1.09	1.88	3.79	0	4.59	6.33	4.59	6.33	5.24	4.59	0.52	1.92	1.09	0.79	1.91	5	5	10
1152	1.08	1.86	3.69	0	4.63	6.41	4.63	6.41	5.46	4.63	0.47	1.96	1.08	0.78	1.83	5	5	10
1153	1.22	2.00	3.76	0	4.10	6.41	4.10	6.41	5.68	4.10	1.16	2.04	1.22	0.78	1.76	5	5	10
1155	1.20	2.03	3.91	0	4.17	6.02	4.17	6.02	5.32	4.17	1.00	2.11	1.20	0.83	1.88	5	5	10
1157	1.19	2.02	3.90	0	4.20	6.02	4.20	6.02	5.32	4.20	0.96	2.11	1.19	0.83	1.88	5	5	10
1169	1.12	1.88	3.70	0	4.46	6.58	4.46	6.58	5.49	4.46	0.70	1.88	1.12	0.76	1.82	5	5	10
1201	0.99	1.74	3.58	0	5.05	6.67	5.05	6.67	5.43	5.05	-0.07	1.81	0.99	0.75	1.84	5	5	10
1203	1.15	1.93	3.73	0	4.35	6.41	4.35	6.41	5.56	4.35	0.84	1.99	1.15	0.78	1.80	5	5	10
1205	1.09	1.90	3.70	0	4.59	6.17	4.59	6.17	5.56	4.59	0.51	2.13	1.09	0.81	1.80	5	5	10
1206	1.15	1.93	3.85	0	4.35	6.41	4.35	6.41	5.21	4.35	0.84	1.87	1.15	0.78	1.92	5	5	10
1208	1.05	1.80	3.39	0	4.76	6.67	4.76	6.67	6.29	4.76	0.32	2.10	1.05	0.75	1.59	5	5	10

Subject 5																		
Timing Gates				Speed (initial)			Speed (final)			Acceleration			Time			Distance		
s				ms-1			ms-1			ms^2			s			m		
Start Time	5m (s)	10m (s)	20m (s)	u5	u10	u20	v5	v10	v20	a5	a10	a20	t5	t10	t20	s5	s10	s20
1144	1.08	1.91	3.70	0	4.63	6.02	4.63	6.02	5.59	4.63	0.45	2.22	1.08	0.83	1.79	5	5	10
1145	1.24	2.06	3.83	0	4.03	6.10	4.03	6.10	5.65	4.03	1.18	2.20	1.24	0.82	1.77	5	5	10
1147	1.18	2.16	4.23	0	4.24	5.10	4.24	5.10	4.83	4.24	0.78	2.37	1.18	0.98	2.07	5	5	10
1149	1.17	2.07	4.04	0	4.27	5.56	4.27	5.56	5.08	4.27	0.81	2.26	1.17	0.90	1.97	5	5	10
1150	1.60	2.72	5.10	0	3.13	4.46	3.13	4.46	4.20	3.13	1.67	2.33	1.60	1.12	2.38	5	5	10
1152	1.50	2.53	4.77	0	3.33	4.85	3.33	4.85	4.46	3.33	1.62	2.30	1.50	1.03	2.24	5	5	10
1154	1.33	2.34	4.64	0	3.76	4.95	3.76	4.95	4.35	3.76	1.23	2.20	1.33	1.01	2.30	5	5	10
1155	1.26	2.20	4.38	0	3.97	5.32	3.97	5.32	4.59	3.97	1.10	2.15	1.26	0.94	2.18	5	5	10
1157	1.21	2.16	4.51	0	4.13	5.26	4.13	5.26	4.26	4.13	0.91	2.02	1.21	0.95	2.35	5	5	10
1159	1.17	2.15	4.36	0	4.27	5.10	4.27	5.10	4.52	4.27	0.74	2.22	1.17	0.98	2.21	5	5	10
1201	1.21	2.26	4.60	0	4.13	4.76	4.13	4.76	4.27	4.13	0.83	2.24	1.21	1.05	2.34	5	5	10
1203	1.37	2.51	4.95	0	3.65	4.39	3.65	4.39	4.10	3.65	1.18	2.30	1.37	1.14	2.44	5	5	10
1205	1.22	2.20	4.42	0	4.10	5.10	4.10	5.10	4.50	4.10	0.92	2.21	1.22	0.98	2.22	5	5	10
1207	1.30	2.26	4.35	0	3.85	5.21	3.85	5.21	4.78	3.85	1.20	2.29	1.30	0.96	2.09	5	5	10
1208	1.15	2.02	4.05	0	4.35	5.75	4.35	5.75	4.93	4.35	0.75	2.10	1.15	0.87	2.03	5	5	10

Appendix E Study 2 High Speed Running Metre

	Week 1			Week 2			Week 3			Week 4			Week 5			Week 6		
	5.0 ms-1	60% Vmax	MAS	5.0 ms-1	60% Vmax	MAS	5.0 ms-1	60% Vmax	MAS	5.0 ms-1	60% Vmax	MAS	5.0 ms-1	60% Vmax	MAS	5.0 ms-1	60% Vmax	MAS
Subject 1	102	75	191	178	147	298	332	257	540	167	80	608	0	0	0	211	133	393
Subject 2	38	25	75	171	259	297	339	259	487	925	602	1429	330	256	400	0	0	7
Subject 3	21	67	66	23	130	53	40	119	118	33	370	360	11	40	37	41	161	157
Subject 4	101	63	157	176	224	281	177	144	249	363	161	895	168	[redacted]	[redacted]	149	77	246
Subject 5	73	98	117	163	160	276	242	361	451	282	585	922	179	301	399	146	216	316
Subject 6	129	129	198	269	311	391	543	543	669	613	613	883	403	403	571	311	311	472
Subject 7	30	37	57	148	103	204	143	176	234	548	634	823	204	232	272	60	77	111
Subject 8	59	104	121	27	262	120	209	318	367	446	905	1107	122	199	245	161	259	316
Subject 9	47	50	93	60	90	166	6	22	74	120	134	213	121	144	297	177	196	348
Subject 10	29	6	38	123	158	158	339	230	437	20	12	32	238	121	328	180	112	220
Subject 11	121	65	139	250	312	292	508	353	552	1332	757	1488	478	353	515	249	191	261
Subject 12	17	76	35	43	191	87	22	140	62	292	935	688	0	76	14	61	191	126
Subject 13	4	29	26	34	222	129	42	105	103	34	362	322	34	154	142	123	241	230
Subject 14	0	44	31	17	96	91	5	80	56	84	621	553	27	151	124	0	0	0
Subject 15	27	114	64	61	185	154	106	404	258	186	911	687	35	171	106	78	284	178
Subject 16	17	145	95	44	204	141	190	190	190	219	1002	718	156	447	359	170	552	404

Appendix F Study 3 Training Load Data

	Week 1			Week 2			Week 3			Week 4			Week 5			Week 6		
	sRPE	Time	TL	sRPE	Time	TL	sRPE	Time	TL	sRPE	Time	TL	sRPE	Time	TL	sRPE	Time	TL
Subject 1	7	75	525	6	85	510	6	68	408	8	87	696	5	65	325	6	65	390
Subject 2		75		6	85	510	5	68	340	9	87	783	7	65	455		65	0
Subject 3		75		6	85	510	6	68	408	7	87	609	6	65	390	4	65	260
Subject 4	6	75	450	6	85	510	5	68	340	8	87	696	7	65	455	5	65	325
Subject 5		75		6	85	510	6	68	408	9	87	783	7	65	455		65	
Subject 6		75		5	85	425	7	68	476	8	87	696	8	65	520	6	65	390
Subject 7	5	75	375	6	85	510	6	68	408	8	87	696	7	65	455	7	65	455
Subject 8		75		6	85	510	5	68	340	9	87	783	7	65	455	5	65	325
Subject 9	7	75	525	5	85	425		68		6	87	522	8	65	520	5	65	325
Subject 10	6	75	450	6	85	510	7	68	476		87		5	65	325	6	65	390
Subject 11	6	75	450	6	85	510	5	68	340	9	87	783	6	65	390	6	65	390
Subject 12	6	75	450	6	85	510	6	68	408	8	87	696	8	65	520	6	65	390
Subject 13		75		6	85	510	5	68	340	7	87	609	7	65	455	5	65	325
Subject 14	7	75	525	7	85	595	6	68	408	8	87	696	7	65	455	6	65	390
Subject 15		75		5	85	425	5	68	340	7	87	609	6	65	390		65	
Subject 16		75		7	85	595	6	68	408	7	87	609	8	65	520	5	65	325

Appendix G Study 2 Testosterone Cortisol Data

	Week 1		Week 2		Week 3		Week 4		Week 5		Week 6	
	T	C	T	C	T	C	T	C	T	C	T	C
Subject 1	225.474	0.244	1239.954	0.700	196.024	0.264	256.782	0.126			522.490	0.154
Subject 2	51.108	0.224	77.699	0.666			192.509	0.175	226.435	0.717	239.567	0.251
Subject 3	208.747	0.529	536.607	0.609				0.163		0.239		0.225
Subject 4	556.488	0.274	63.526	0.398	306.871	0.347	635.694	0.244	382.928	0.131	156.682	
Subject 5	37.910	0.093	271.405	0.398		0.282	515.009	0.081	2618.381	0.603		0.322
Subject 6	54.603	0.297	921.511	0.417	359.921	0.781	663.749	0.721	267.571	0.347	219.822	0.312
Subject 7	72.161	0.288	194.038	0.301	518.099	0.387		0.057		0.663		0.261
Subject 8	70.473	0.156	380.254	0.601	208.742	0.307	402.317	0.105	402.317	0.267	310.006	0.174
Subject 9	67.569	0.172		0.390	224.894	0.558	1389.524	0.234		0.462		0.272
Subject 10	1771.240	31.335		0.840	285.695	0.249	71.601	0.303				
Subject 11	126.117	0.320	1705.824	0.356	282.820	0.353		0.182		0.774		0.254
Subject 12	128.292	0.200			71.743	0.053	215.062	0.182		0.056	196.464	0.160
Subject 13	56.716	0.509		0.294	1352.716	0.096		0.124		0.065		0.161
Subject 14	65.383	0.237	60.192	0.815		0.472		0.215	301.982	0.576		
Subject 15	301.900	0.416		0.486		0.163	972.594			0.171		0.201
Subject 16	109.685	0.222	407.193	0.757	320.584	0.302	2416.925			0.162		0.194

Appendix H Study 3 Training Load Data

Acute

Subject	Week -3	Week -2	Week -1	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Average	SD
1	1368	320	1620	2410	750	1465	2240	2395	2935	3140	2295	2592	1675	740	2058	769
2	1395	1640	0	1925	2290	1610	3082	2233	1918	1890	1600	1856	1795	1715	1992	403
3	1970	1115	835	1800	1315	1705	2917	1889	0	2200	2165	1850	2320	945	1737	738
4	1425	1115	1045	1660	1795	2185	2264	2022	2242	2110	2103	1320	2205	1476	1944	314
5	1200	1225	650	3440	3530	1885	2760	2650	2515	2615	4140	2190	1815	1160	2609	817
6	1770	620	835	2751	1760	1940	2727	2264	2415	300	1656	2126	1995	1250	1926	669
7	1185	1160	965	3325	960	2430	2502	2155	1968	1690	1280	2101	2255	1928	2054	600
8	1908	720	965	1900	3340	1780	2944	1893	1968	2185	2221	2236	1950	1285	2155	535
9	1205	1075	1620	3240	2595	880	2402	2353	1680	2175	1890	1716	2220	1758	2083	579
10	635	1320	490	2170	2245	1475	2959	2508	1683	0	2107	2120	1965	1630	1897	719
11	1448	1465	1530	2410	3355	2580	1487	1670	2190	1665	2935	1530	2215	1355	2127	621
12	0	540	1440	1900	1605	2240	1985	2526	2415	1885	1550	2180	2390	995	1970	434
13	1658	765	980	1905	2360	1965	3534	1867	984	2280	2111	1466	1925	1660	2005	606
14	700	625	1620	2979	2440	2735	1505	1668	1513	1210	1425	2141	2485	1828	1994	566
15	820	1340	615	825	2080	2730	1270	1140	1605	1410	2100	1965	1730	1935	1708	509
16	1265	465	1170	1290	2355	2105	1610	1345	1974	2195	1320	2400	1530	1127	1750	445
Average	1247	969	1024	2246	2173	1982	2387	2036	1875	1809	2056	1987	2029	1424		
SD	496	380	450	723	783	488	643	418	660	768	681	334	270	360		

Chronic

Subject				Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Average	SD
1				1430	1275	1561	1716	1713	2259	2678	2691	2741	2426	1826	2029	519
2				1240	1464	1456	2227	2304	2211	2281	1910	1816	1785	1742	1858	352
3				1430	1266	1414	1934	1957	1628	1752	1564	1554	2134	1820	1677	254
4				1311	1404	1671	1976	2067	2178	2160	2119	1944	1935	1776	1867	283
5				1629	2211	2376	2904	2706	2453	2635	2980	2865	2690	2326	2525	370
6				1494	1492	1822	2295	2173	2337	1927	1659	1624	1519	1757	1827	302
7				1659	1603	1920	2304	2012	2264	2079	1773	1760	1832	1891	1918	218
8				1373	1731	1996	2491	2489	2146	2248	2067	2153	2148	1923	2070	306
9				1785	2133	2084	2279	2058	1829	2153	2025	1865	2000	1896	2010	146
10				1154	1556	1595	2212	2297	2156	1788	1575	1478	1548	1956	1756	342
11				1713	2190	2469	2458	2273	1982	1753	2115	2080	2086	2009	2103	233
12				970	1371	1796	1933	2089	2292	2203	2094	2008	2001	1779	1867	369
13				1327	1503	1803	2441	2432	2088	2166	1811	1710	1946	1791	1910	335
14				1481	1916	2444	2415	2087	1855	1474	1454	1572	1815	1970	1862	338
15				900	1215	1563	1726	1805	1686	1356	1564	1770	1801	1933	1574	292
16				1048	1320	1730	1840	1854	1759	1781	1709	1972	1861	1594	1679	258
Average				1371	1603	1856	2197	2145	2070	2027	1944	1932	1970	1874		
SD				254	326	328	312	255	242	356	402	379	285	155		

A:C Ratio

Subject				Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Average	SD
1				1.69	0.59	0.94	1.31	1.40	1.30	1.17	0.85	0.95	0.69	0.41	1.03	0.37
2				1.55	1.56	1.11	1.38	0.97	0.87	0.83	0.84	1.02	1.01	0.98	1.10	0.26
3				1.26	1.04	1.21	1.51	0.97	0.00	1.26	1.38	1.19	1.09	0.52	1.04	0.41
4				1.27	1.28	1.31	1.15	0.98	1.03	0.98	0.99	0.68	1.14	0.83	1.06	0.19
5				2.11	1.60	0.79	0.95	0.98	1.03	0.99	1.39	0.76	0.67	0.50	1.07	0.44
6				1.84	1.18	1.07	1.19	1.04	1.03	0.16	1.00	1.31	1.31	0.71	1.08	0.39
7				2.00	0.60	1.27	1.09	1.07	0.87	0.81	0.72	1.19	1.23	1.02	1.08	0.36
8				1.38	1.93	0.89	1.18	0.76	0.92	0.97	1.07	1.04	0.91	0.67	1.07	0.33
9				1.82	1.22	0.42	1.05	1.14	0.92	1.01	0.93	0.92	1.11	0.93	1.04	0.31
10				1.88	1.44	0.92	1.34	1.09	0.78	0.00	1.34	1.43	1.27	0.83	1.12	0.47
11				1.41	1.53	1.05	0.60	0.73	1.11	0.95	1.39	0.74	1.06	0.67	1.02	0.30
12				1.96	1.17	1.25	1.03	1.21	1.05	0.86	0.74	1.09	1.19	0.56	1.10	0.34
13				1.44	1.57	1.09	1.45	0.77	0.47	1.05	1.17	0.86	0.99	0.93	1.07	0.31
14				2.01	1.27	1.12	0.62	0.80	0.82	0.82	0.98	1.36	1.37	0.93	1.10	0.37
15				0.92	1.71	1.75	0.74	0.63	0.95	1.04	1.34	1.11	0.96	1.00	1.10	0.34
16				1.23	1.78	1.22	0.88	0.73	1.12	1.23	0.77	1.22	0.82	0.71	1.06	0.31
Average				1.61	1.34	1.09	1.09	0.95	0.89	0.88	1.06	1.05	1.05	0.76		
SD				0.34	0.37	0.27	0.27	0.20	0.29	0.33	0.24	0.22	0.20	0.19		

Appendix I Study 3 Counter Movement Jump Data

Subject	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Average	SD
1	52.4	53.6	53.4	53.4		55.2	54.8	52.8	56.5		51.3	53.7	1.5
2	57.2	61.2	59	60.4	57.9	60.6	60.6					59.6	1.4
3		51.8	54.9	53.3	53.6		52.8	52.1	50.7	54.4		53.0	1.3
4	49.4	47.8	46.8	49.8	49.7	47.2	49.2	47.9	47.9	49.4	48.7	48.5	1.0
5	46.7	46.8	44.4	48.6		46.8	48.9	47.1	47	47.6	50.1	47.4	1.5
6	51.3	50.6	49.7	51.8	52.6	54.1		47	48.4	50.1	54.4	51.0	2.2
7	48.7	47.6	47	45.3	47.2	47.9	47.2		44.7	48	50.5	47.4	1.5
8		51.6	46.5	49.8	47.5	50.2	47.8	49.1	46.2	45.9	47.6	48.2	1.8
9	44.9	47.4		49	47.9	50.2	48.6	49.9	45.8	46.1	49	47.9	1.7
10	46.2	49.8	45.9	48	47.9	48.5		47.1	46.5	44.6	50.5	47.5	1.7
11	47	48	42.2	50.4		48.2	50.1	50.7	52.1	47.3	47.9	48.4	2.6
12	42.1	44.5	41	43.8	41	40.3	44.3	38.7	43.1	41.5	39.8	41.8	1.8
13	59.2	63.2	62	60.2	59.9	63.0	60.4	59.7	54.5	56.7	62	60.1	2.5
14	42.8	44.9	47.6		43.3	48.0	44.4	47.7	46.1	45.6	48.7	45.9	2.0
15			47.6									47.6	0.0
16			51.8	50.3	52.7	54.7	49.4	48.7	48.5	50.2	53.6	51.1	2.1
Average	49.0	50.6	49.3	51.0	50.1	51.1	50.7	49.1	48.4	48.3	50.3		
SD	5.1	5.4	5.7	4.6	5.3	5.7	5.0	4.5	3.6	3.9	4.8		

Appendix J Study 3 Body Weight Data

Subject	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Average	SD
1	117.5	116.6	116.5	115.7	116.4	116.8	116.4	116.2	115.0	116.4	116.3	116.3	0.6
2	88.5	88.6	89.4	89.5	89.5	86.3	88.3	88.8	88.9	89.5	89.5	88.8	0.9
3	88.3	[redacted]	89.8	90.4	89.0	90.2	90.0	89.4	88.8	89.4	89.2	89.5	0.6
4	106.7	107.0	107.0	106.5	105.6	106.0	105.3	106.4	106.2	104.5	105.5	106.1	0.7
5	114.5	115.0	115.0	115.0	114.9	116.0	115.0	115.0	115.0	115.5	115.5	115.1	0.4
6	91.6	90.6	91.4	89.7	88.7	89.0	89.1	88.7	88.3	88.0	87.9	89.4	1.2
7	106.6	105.2	105.4	106.1	105.3	105.0	106.5	105.8	106.9	106.0	106.8	106.0	0.6
8	109.2	109.3	109.5	109.7	109.5	109.0	109.3	109.4	109.2	109.5	109.7	109.4	0.2
9	104.6	103.6	[redacted]	104.1	103.4	104.4	104.4	105.4	105.5	105.6	104.8	104.6	0.7
10	88.2	88.4	88.4	88.5	88.6	88.3	[redacted]	88.2	88.9	88.0	88.4	88.4	0.2
11	104.4	104.1	104.3	104.3	104.0	104.3	104.0	104.2	103.8	103.7	101.7	103.9	0.7
12	99.3	99.2	100.1	100.3	100.2	100.4	100.1	101.0	100.1	100.2	100.8	100.2	0.5
13	85.0	86.0	86.0	86.0	86.6	85.0	85.0	85.0	85.0	85.0	86.0	85.5	0.6
14	104.5	104.8	104.4	103.0	104.1	104.2	104.0	104.4	104.5	104.5	104.6	104.3	0.5
15	84.8	83.5	82.4	82.2	83.7	84.0	82.8	82.3	82.1	82.0	82.0	82.9	0.9
16	103.5	103.4	104.1	104.8	103.1	104.4	104.9	105.6	104.7	104.6	104.6	104.3	0.7
Average	99.8	100.4	99.6	99.7	99.5	99.6	100.3	99.7	99.6	99.5	99.6		
SD	10.3	10.2	10.5	10.2	10.1	10.5	10.3	10.6	10.5	10.6	10.5		

Appendix K Study 3 Groin Squeeze Data

Subject	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Average	SD
1	270	280	260	280	290	290	290	300	300	290	290	285.5	11.6
2	270	260	260	260	250	220	250	260	260	260	260	255.5	12.3
3	290		270	300	290	260	280	310	280	280	300	286.0	14.3
4	240	250		250	230	230	250	280	260	230	270	249.0	16.4
5	220	220	220	220	230	240	220	250	220	210	230	225.5	10.8
6	210	280	240	260	260	250	200	260	280	250	180	242.7	31.1
7	290	260	280	300	260	300	280	290	300	290	280	284.5	13.7
8	250	240	240	230	260	270	260	270	250	270	240	252.7	13.5
9	270	270		290	280	270	290	300	280	270	280	280.0	10.0
10	300	310	310	310	300	300		300	300	300	300	303.0	4.6
11	210	230	160	200	240	280	260	220	200	200	200	218.2	31.6
12	160	180	190	180	180	160	180	180	200	160	180	177.3	12.1
13	280	290	270	280	270	300	270	260	220	280	300	274.5	21.0
14	240	250	240	260	240	230	250	260	220	250	280	247.3	15.4
15	240	250	240	240	240	250	250	250	260	240	260	247.3	7.5
16	260	260	260	260	260	270	260	260	260	260	250	260.0	4.3
Average	250.0	255.3	245.7	257.5	255.0	257.5	252.7	265.6	255.6	252.5	256.3		
SD	35.7	30.1	36.2	35.6	28.5	35.6	30.4	32.0	33.3	36.3	39.2		

Appendix L Study 3 Mood Data

Subject	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Average	SD
1	7	7	8	8	7	7	8	6	8	8	6	7.3	0.7
2	7	7	7	7	7	7	7	6	7	7	7	6.9	0.3
3	7	9	9	7	9	7	7	7	9	9	6	7.8	1.1
4	8	8	8	8	9	9	8	9	8	9	9	8.5	0.5
5	8	6	8	1	8	9	8	6	8	6	10	7.1	2.3
6	7	7	6	7	7	8	7	8	7	8	8	7.3	0.6
7	8	6	8	7	8	8	8	8	8	8	8	7.7	0.6
8	8	7	8	9	7	7	7	7	8	8	7	7.5	0.7
9	6	8		8	8	8	9	8	8	7	9	7.9	0.8
10	9	9	10	9	10	9		8	9	9	9	9.1	0.5
11	7	7	8	7	5	6	6	7	7	6	7	6.6	0.8
12	10	10	10	10	10	10	10	10	10	10	10	10.0	0.0
13	7	8	6	9	8	6	8	8	8	7	8	7.5	0.9
14	8	8	7	3	8	8	9	8	6	9	9	7.5	1.7
15	7	7	7	7	6	7	7	6	7	7	7	6.8	0.4
16	7	6	8	8	8	8	7	8	8	8	8	7.6	0.6
Average	7.6	7.5	7.9	7.2	7.8	7.8	7.7	7.5	7.9	7.9	8.0		
SD	0.9	1.1	1.1	2.2	1.3	1.1	1.0	1.1	0.9	1.1	1.2		

Appendix M Study 3 Stress Data

Subject	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Average	SD
1	2	4	3	3	1			3	3	4	3	2.9	0.9
2	1	1	1	1	2	2	2	2	2	2	2	1.6	0.5
3	2	3	2	3	3	3	4	2	2	2	4	2.7	0.7
4	4	2	2	2	2	2	1	2	1	2	2	2.0	0.7
5	3	3	2	5	2	1	2	4	3	4	1	2.7	1.2
6	2	2	2	1	2	2	2	3	2	2	2	2.0	0.4
7	2	2	2	2	2	2	2	1	1	2	1	1.7	0.4
8	2	4	3	2	3	3	2	3	3	2	2	2.6	0.6
9	4	4		1	3	3	2	3	2	2	3	2.7	0.9
10	2	2	1	2	2	2		2	2	2	2	1.9	0.3
11	5	3	1	3	3	2	3	3	3	2	4	2.9	1.0
12	1	2	1	1	1	2	1	1	1	2	1	1.3	0.4
13	1	2	2	2	2	2	2	2	2	2	3	2.0	0.4
14	1	1	1	3	2	1	3	2	3	2	1	1.8	0.8
15	1	1	1	1	2	1	1	1	1	1	1	1.1	0.3
16	2	2	3	2	2	2	3	3	2	2	3	2.4	0.5
Average	2.2	2.4	1.8	2.1	2.1	2.0	2.1	2.3	2.1	2.2	2.2		
SD	1.2	1.0	0.7	1.1	0.6	0.6	0.8	0.8	0.7	0.7	1.0		

Appendix N Study 3 Soreness Data

Subject	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Average	SD
1	3	2	2	1	[redacted]	2	2	1	1	2	3	1.9	0.7
2	3	1	1	1	2	2	2	2	1	2	2	1.7	0.6
3	2	2	1	2	3	2	2	2	3	1	4	2.2	0.8
4	2	3	2	2	3	3	1	2	1	2	4	2.3	0.9
5	4	1	4	4	3	1	1	2	3	4	1	2.5	1.3
6	3	3	2	2	3	2	2	1	3	2	3	2.4	0.6
7	4	2	2	2	3	4	2	1	1	1	3	2.3	1.1
8	2	4	5	2	3	3	2	3	3	2	2	2.8	0.9
9	3	2	[redacted]	2	3	3	2	2	2	2	2	2.3	0.5
10	2	2	2	2	2	3	[redacted]	2	3	2	3	2.3	0.5
11	4	4	2	3	4	2	3	3	3	5	3	3.3	0.9
12	1	2	2	1	1	1	1	2	1	4	2	1.6	0.9
13	2	2	2	3	3	2	2	2	2	2	4	2.4	0.6
14	2	1	2	1	2	2	2	2	1	2	1	1.6	0.5
15	3	1	1	1	1	1	1	1	1	1	1	1.2	0.6
16	3	1	3	2	3	2	3	1	3	2	4	2.5	0.9
Average	2.7	2.1	2.2	1.9	2.6	2.2	1.9	1.8	2.0	2.3	2.6		
SD	0.8	1.0	1.0	0.8	0.8	0.8	0.6	0.6	0.9	1.1	1.1		

Appendix O Study 3 Fatigue Data

Subject	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Average	SD
1	2	3	3	3	2	2	3	4	2	3	3	2.7	0.6
2	1	1	1	1	2	2	1	1	2	1	2	1.4	0.5
3	2	2	1	2	3	2	3	3	2	2	2	2.2	0.6
4	2	2	1	2	3	2	2	2	1	2	3	2.0	0.6
5	6	1	3	4	3	1	3	3	2	5	1	2.9	1.6
6	3	3	2	2	3	2	2	1	3	2	2	2.3	0.6
7	2	2	2	4	4	3	2	2	2	2	2	2.5	0.8
8	1	3	4	3	3	3	2	3	4	2	3	2.8	0.8
9	2	2	[redacted]	2	3	2	1	2	2	2	2	2.0	0.4
10	2	2	2	2	2	2	[redacted]	2	2	2	3	2.1	0.3
11	4	4	2	4	5	3	3	3	4	7	4	3.9	1.2
12	1	1	2	1	2	2	1	2	1	3	3	1.7	0.7
13	3	1	5	2	3	4	2	2	2	2	3	2.6	1.1
14	2	1	1	4	3	2	2	2	2	1	1	1.9	0.9
15	1	2	2	1	2	1	1	2	1	1	1	1.4	0.5
16	4	2	3	2	2	1	2	2	3	2	4	2.5	0.9
Average	2.4	2.0	2.3	2.4	2.8	2.1	2.0	2.3	2.2	2.4	2.4		
SD	1.3	0.9	1.1	1.1	0.8	0.8	0.7	0.8	0.9	1.5	0.9		

Appendix P Study 3 Sleep Data

Subject	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Average	SD
1	7	7	8	7	7	7	8	7	7	8	8	7.4	0.5
2	7	6	6	6	7	7	7	7	7	8	7	6.8	0.6
3	7	7	5	7	9	9	6	3	7	9	8	7.0	1.8
4	7	8	6	7	8	7	6	9	6	9	9	7.5	1.2
5	7	7	9	8	8	10	5	6	8	7	10	7.7	1.5
6	5	6	5	6	6	6	6	6	5	6	5	5.6	0.5
7	7	6	7	7	7	7	5	8	8	9	7	7.1	1.0
8	8	8	8	8	8	7	6	8	8	8	8	7.7	0.6
9	8	8	[redacted]	9	8	9	9	9	8	8	8	8.4	0.5
10	9	10	9	9	9	9	[redacted]	9	9	9	9	9.1	0.3
11	7	7	8	5	7	7	7	7	7	7	7	6.9	0.7
12	10	10	10	10	10	10	10	10	9	9	8	9.6	0.6
13	7	9	4	7	7	7	8	8	8	8	9	7.5	1.3
14	6	8	8	8	8	8	5	8	9	8	8	7.6	1.1
15	7	7	7	7	7	7	7	7	7	7	7	7.0	0.0
16	8	7	8	7	9	9	8	8	8	8	8	8.0	0.6
Average	7.3	7.6	7.2	7.4	7.8	7.9	6.9	7.5	7.6	8.0	7.9		
SD	1.1	1.2	1.6	1.2	1.0	1.2	1.5	1.6	1.1	0.9	1.1		

Appendix Q Study 3 Testosterone Data

Subject	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Average	SD
1	[redacted]	702.2	434.7	943.2	980.1	179.9	1262.8	491.6	902.8	1205.6	1208.6	831.1	349.5827
2	[redacted]	-258.0	456.5	1214.7	1043.8	154.9	1317.6	639.8	1231.1	1161.2	1050.7	801.2	505.7457
3	[redacted]	127.5	810.4	937.8	633.9	1436.4	1380.4	912.0	581.0	749.2	1164.7	873.3	371.8957
4	[redacted]	157.1	700.6	599.3	619.8	1525.8	1617.2	411.9	803.3	406.4	547.8	738.9	449.7109
5	[redacted]	418.7	863.2	828.9	688.0	1597.6	1526.8	793.6	1480.2	1003.9	1141.6	1034.2	374.0729
6	[redacted]	1089.8	1117.1	1473.1	802.3	1323.6	992.2	1351.2	1287.3	1202.3	1333.5	1197.2	189.3336
7	[redacted]	799.7	679.7	-312.5	574.3	1637.7	1194.8	1249.3	716.1	965.3	804.9	830.9	488.6038
8	[redacted]	259.4	847.0	359.0	437.7	1622.0	1328.4	608.0	1179.8	928.3	835.8	840.5	419.2335
9	[redacted]	1028.2		966.1	1232.4	1501.6	1414.9	949.9		773.0		1123.7	246.8592
10	[redacted]	850.4	897.9	1107.6	239.5	1553.8		680.1	595.5	1297.4	1162.5	931.6	375.3628
11	[redacted]	747.0	155.3	239.0	900.5	1168.3	1334.6	513.2	1200.3	840.3	1065.7	816.4	384.2996
12	[redacted]	793.4	1181.2	540.0	1326.2	925.8	1373.5	734.6	1278.7	1489.3	517.0	1016.0	340.1251
13	[redacted]	1189.2	726.5	-279.2	1198.7	1680.2	1067.5	985.7	1109.9	1312.0	1090.3	1008.1	486.8883
14	[redacted]	1150.5	1083.5	681.3	1224.4	1644.2	-1658.7	1005.0	1037.9	1020.9	1225.9	841.5	864.1148
15	[redacted]	747.0	747.7	239.0	2067.3	1168.3	1622.2	513.2	897.3	840.3	1341.6	1018.4	514.5576
16	[redacted]	391.0	959.6	1597.6	1942.6	1918.9	1863.4	667.8	1896.6	-1379.1	1933.6	1179.2	1016.493
Average	[redacted]	637.1	777.4	695.9	994.5	1314.9	1175.8	781.7	1079.9	863.5	1094.9		
SD	[redacted]	402.5938	265.7762	536.1089	486.0745	491.4506	786.7486	264.6661	338.3174	633.4857	331.6985		