THE UNIVERSITY OF HULL

THE EFFECT OF BIO-BANDING AND PITCH SIZES ON DIFFERENTIAL RATINGS OF PERCEIVED EXERTION (DRPE)

Master of Research

In the University of Hull

by

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May 2021

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Acknowledgements

Firstly, I would like to thank my supervisors who formed my research team throughout. Dr Chris Towlson, Dr Steve Barrett and Dr Grant Abt who were always there for me when I needed them most. They were always available to talk and were always quick and responsive with their feedback. I feel that their support and guidance has made me a better learner and student, so they receive a big thank you. Secondly, I would like to thank my family for their continued love and care, ever since I made the decision to move to Hull in 2015, they have encouraged me to pursue my dreams and have very often made the trip to see me. Once during my second year Gary, my mam's partner, travelled all the way to Hull just to drop off a printer, this is roughly a 6-hour round trip. The love I have towards my family is unimaginable. I would like to thank the football clubs who allowed me to come in and use their facilities and players in name of research. A special thanks must go to Hull City it has been my privilege to step up into the role of MRes student from undergraduate intern. The opportunities and experience you have afforded me in my 4 ½ years at the club are something that I will never forget. Hopefully I can pursue a career in elite football but thank you for taking the risk on a young and naïve football coach and turning him into a sports scientist. Lastly, I would like to thank Georgie who's support in the final stages of my thesis definitely helped to push me over the finish line.

Abstract:

Little research exists on the use of differential ratings of perceived exertion (dRPE) in youth soccer, with no research during bio-banded small-sided games (SSGs). Bio-banding categorises players based upon maturity status rather than chronological age. Differential ratings of perceived exertion allows for the discrimination of acute sensory inputs by separating various facets of effort. The aim of the study was to explore the influence of relative pitch-size during bio-banded SSGs on academy soccer players dRPE. Forty-three youth (U12 to U14) soccer players from a category 1 and 2 academy participated in maturity matched/mis-matched bio-banded SSGs. The SSGs were played on increasing relative pitch sizes; small (17 m x 17 m (36 m^2)), medium (24 m x 24 m (72 m^2)) large (29.5 m x 29.5 m (109 m^2)) and expansive (34 m x 34 m (144.5 m^2)). Each player was equipped with a foot-mounted inertial measurement unit (IMU), a heart rate (HR) monitor and a micro-electromechanical sensor (MEMS) device to quantify technical output and external load respectively. Players were banded according to the Khamis and Roche maturity estimation method using modified thresholds to determine post-peak height velocity (PHV) (90-95.9% estimated adult stature attained (EASA)) and pre-PHV (84-89.9% EASA). Players gave their dRPE using the CR-100 category-ratio scale, accompanied by an adapted pictorial walking/running OMNI Scale. It was found that pre-PHV players consistently rated a significantly greater (*p = 0.000 –0.0.029, moderate – large*) mean RPE-Technical/Tactical/Cognitive (RPE-T) than their post-PHV counterparts. This research is the first to explore the use of dRPE during bio-banded SSGs. The findings suggest there is little usefulness in the collection of dRPE within the youth population in soccer SSGs. It does offer support for maturity matched bio-banding, as an effective training method in youth soccer. Further research is recommended into the usefulness of collecting dRPE as a means of measuring internal load in youth soccer players.

1.0 Introduction

1.1 Soccer

Association football, otherwise known as soccer, is regarded as the world's most popular sport and is enjoyed by men and women of all ages (Stølen, Chamari, Castagna & Wisløff, 2005). Many young fans make it their dream to become a professional soccer player. The popularity of soccer spans culturally diverse societies across the globe (Giulianotti & Robertson, 2004). Despite the rather outdated figures, Giulianotti and Robertson (2004) reported that around 250 million people are directly involved in soccer participation. FIFA (Fédération Internationale de Football Association) reported a 20 million participant increase in the 3 years that followed, in their 2007 investigation. Giulianotti and Robertson (2004) reported than an estimated 1.4 billion individuals are interested in soccer with the World Cup attracting a reported global television audience of 33.4 billion across all games. In 1998 it was told FIFA controlled a number of contracts worth a projected £4 billion (Giulianotti & Robertson, 2004). In 2001, FIFA recorded a turnover of approximately £250 billion, a figure equivalent to the gross domestic product of the Netherlands (Walvin, 2001). There is an assumption that the commercial power of FIFA has rose year upon year since, as soccer has become more popular and in turn an enhanced commercial prospect.

In theory, soccer is a relatively simple game as eleven players on either team aim to outscore the opposition, by placing the ball in the oppositions goal. However, soccer is a demanding sport both physiologically and cognitively for both players, coaches and officials. Due to the commercial nature of modern soccer, there is a greater emphasis upon success, and therefore a greater stress upon players and coaches to deliver positive results. To understand the enormity of the commercial side of soccer in England, the Premier League in the 2018/2019 season paid a total sum of

£2,456,008,346 split between all 20 clubs, based upon various considerations. The 20 clubs received money based upon their finishing position with each position being worth roughly £2 million (1st - £38,370,360; 10th - £21,103698; 20th - £1,918,518). Each club also received the same equal payments from UK Television, International Television and Commercial (£34,361,519, £43,184,608, £4,965,392, respectively) (Premier League, 2019). These figures are only likely to increase further as more broadcasters get involved with elite level soccer, as recently as the 2019/2020 season, Amazon bought the television rights to two full fixture weeks (20 games), joining Sky Sports and BT Sport as a major UK commercial partner for the Premier League, which is thought to be worth well over £4 billon (Burrows, 2018).

1.2 Youth Soccer Academy

The aim of a club's youth academy is to identify young players who will eventually develop into first team players (Unnithan, White, Georgiou, Iga and Drust, 2012). Due to the vast figures associated with player transfers and the commercial gains from soccer players today, there is a growing importance on how best to nurture the next generation of talented soccer players (Mills, Butt, Maynard & Harwood, 2014). The Director of Youth at the Premier League was quoted the following: "the focus on youth has never been as intense or as urgent since the inception of the Premier League as it is right now" (The Premier League, 2012). It is argued that one's chance of success is influenced by the environment (Reilly, Williams & Richardson, 2003) (e.g., the facilities of the club) as well as their own innate, psychological, and physiological characteristics (Mills, Butt, Maynard & Harwood, 2012). The interactions that players have between key stakeholders (parents, coaches, peers) along their journey within an academy, play a central role within their individual development (Richardson, Gilbourne & Littlewood, 2004). As such, the environment created by the individual club's academy is one of the most directly controllable elements of a young players development (Mills et al., 2014). There is a major problem in the number of young players who make it at the top level, in the fact the chances are simply so small. Gordon Taylor, the chief executive of the Professional Footballer's Association (PFA) has alleged that through PFA research it has been found that of the boys accepted onto the elite scholarship programme at 16 years old, only 1 out of every 6 is playing professionally at the age of 21 (Conn, 2017).

1.3 Elite Player Performance Plan

The Elite Player Performance Plan (EPPP) is a long-term strategy with the aim of developing more and better home-grown players (Premier League, n. d.). The EPPP sets out in detail the processes and criteria necessary to create a world leading academy system in England (Premier League, 2011). The goal of the EPPP is to produce better home-grown players with a greater emphasis on the efficacy of investment in youth development (Premier League, 2011). The EPPP details 6 fundamental principles that they regard as critical for success; increase the number and quality of home-grown players earning professional contracts, create more time for players to play and be coached, improve coaching provision, implement a system of effective measurement and quality assurance, positively influence strategic investments in academies and seek to apply significant gains in all aspects of players development (Premier League, 2011). Within the EPPP, four different academy categorisations are detailed. There are several factors that influence which category is assigned to an academy, including but not limited to; productivity rates, coaching and training facilities (Premier League, n. d.). The higher categorisation the academy obtains, the greater the funding they receive

(Premier League, n. d.). Category 4 (Late Development Model) academies neglect youth development and focus solely on the professional development phase with academy registration commencing at U17. As recently as 2017, Huddersfield Town regressed from a category 2 academy to a category 4, citing the reason for this being the rules enforced by the EPPP as well as a number of larger clubs with category 1 status within their operating range (Threlfall-Sykes, 2017). Category 3 (Entry Level Development Model) allows for players registration at U9 level and only requires full time staff in the professional development phase. Coaching access to players is typically up to and around 3,600 hours, based on a 40-week season (Premier League, 2011). Category 2 (The Development Model) offers players access up to and around 6,600 hours of coaching, with a requirement for a greater number of full-time staff. Category 1 (The Optimum Development Model) affords players up to 8,500 hours of coaching provision with again a greater requirement for full-time staff compared to category 2 (Premier League, 2011).

The performance pathway is the process of developing players all the way through the academy from U5-U21 and then eventually into the first team, the performance pathway separates this process into three distinct phases: Foundation Phase (FP), Youth Development Phase (YDP) and Professional Development Phase (PDP) (Premier League, 2011). The FP covers the U5-U11 age groups, the YDP covers U12-U16 with the PDP overseeing the U17-U21 age groups (Premier League, 2011). The performance pathway not only oversees coaching provisions at each phase but also the games programme, sports science & medicine and the education programme (Premier League, 2011). Although the formal registration processes for academies commences at U9's, the EPPP regulates the U5-U8 age groups in development centres to ensure the process of graduating to the academy programme is smooth and continuous (Premier League, 2011).

The ‘charter for quality’ was a plan produced and implemented by the FA in 1998 to establish a two-tier youth system in professional clubs consisting of academies and centres of excellence (Premier League, 2011). Through a comparative study, conducted by the Premier League, it was discovered that the ‘charter for quality’ was vastly behind other major European leagues (Holland, France & Spain). Across all phases of development, the ‘charter for quality’ offered less coaching hours than those in other major European leagues, in total ‘the charter for quality’ offered 9-11 year olds 3 hours per week, 12 – 16 year olds 5 hours per week, 17 – 21 year olds 12 hours per week, totalling in 3760 hours per season, based on a 40 week season, this is compared to Holland (4.5 hrs, 10-12 hrs, 16 hrs, 5,940 hrs), France (4.5 hrs, 10 hrs, 16 hrs, 5,740 hrs) and Spain (3-5 hrs, 6 hrs, 16 hrs, 4,880 hrs), all European figures are based on a typical club (Premier League, 2011).

1.4 Talent identification

Talent identification is the process of distinguishing those with the potential to perform at the elite level (Williams & Reilly, 2000). Traditionally, talent identification was a subjective view of talent from the perspective of a coach or scout (Williams & Reilly, 2000). However, recently there has been a greater emphasis of a more holistic approach to talent identification in youth soccer, through the use of science-based support (Reilly, Williams, Nevill & Franks, 2000; Waldron & Worsfold, 2010). A number of factors have been utilised in both isolation and combination of one another, as predictors of talent, these measures include physiological (Le Gall, Carling, Williams & Reilly, 2010), anthropometrical (Gil, Ruiz, Irazusta, Gil & Irazusta, 2007), psychological

(Williams, 2000), sociological (Meylan, Cronin, Oliver & Hughes, 2010) and technical skills (Figueiredo, Gonçalves, Silva & Malina, 2009a). The shift towards a more science-based focus provides greater detail and objectivity in what is a relatively complex process (Vaeyens, Lenoir, Williams & Philippaerts, 2008). Despite a general acceptance of a more holistic approach to talent identification the practicality of such is far from simple within a soccer academy (Reilly et al., 2000; Carling, Le Gall, Reilly & Williams, 2009).

A successful talent model requires the ability to discriminate between an athlete's adolescent performance level and future potential (Vaeyens et al., 2008). There is often a degree of uncertainty attached with any players perceived potential (Pearson, Naughton & Torode, 2006). Predicting a player's future performance is a difficult task due to the rapid physiological and anthropometrical changes that occur during one's growth (Helsen, Hodges, van Winckel & Starkes, 2000; Pearson et al., 2006; Vaeyens et al., 2008; Meylan et al., 2010), therefore one's future potential is not stable (Abbott & Collins, 2002). The characteristics that ultimately separate elite and sub-elite players may not be detectable until late adolescents (Williams & Reilly, 2000). Consequently, talent identification and talent development should reflect long-term athletic development, as opposed to a short-term success narrative (Reilly et al., 2000; Burgess & Naughton, 2010).

1.4.1 Small Sided Games as a tool for talent identification

Professional soccer clubs run their own youth academy, with the aim of identifying and nurturing local talent from an early age who could one day play for the senior team (Reilly & Gilbourne, 2003). Traditionally, the scout or coach would offer their subjective opinion of a player, whether they deemed them good enough or not

(Unnithan et al., 2012) and this technique used in isolation can often result in misjudgements (Meylan et al., 2010). The usefulness of this technique has been criticised, due to its low predictive value (Vaeyens et al., 2008). It has been suggested an approach that simultaneously allows for the assessment of technical skills and physical attributes is essential in soccer talent identification (Unnithan et al., 2012). The use of small-sided games (SSGs) may play a fundamental role in talent identification models (Fenner, Iga & Unnithan, 2016). Small sided games can replicate the technical, physical and movement demands of competitive match play (Hill-Haas, Dawson, Impellizzeri & Coutts, 2011). By altering the pitch size, the physiological and technical outcomes of the SSGs can be altered (Kelly & Drust, 2009; Dellal et al., 2011b).

1.4.2 Biological maturity in talent identification

Large variations, in physical maturity, between players of the same age group can create challenges in the talent identification process (Abbott, Williams, Brickley & Smeeton, 2019). Physically mature athletes may prevent technical skills of those less physically mature from emerging which may lead to their premature release from talent identification programmes (Reeves, Enright, Dowling & Roberts, 2018). A solution to the problem is to group players based upon their biological maturation, a technique known as bio-banding (Baxter-Jones, 1995; Cumming, Lloyd, Oliver, Eisenmann & Malina, 2017a). Bio-banding is thought to promote competitive equity by reducing the effect of physical advantage (Cumming et al., 2017a). However, it must be stressed that for the holistic development of soccer players, bio-banded competition should be used as a supplement to chronological age competition, not a replacement (Abbott et al., 2019). Bio-banded competition places a unique technical demand on players without reducing the physical demands (Abbott et al., 2019).

1.5 The use of differential ratings of perceived exertion in youth soccer

The use of differential ratings of perceived exertion (dRPE) in youth soccer is a new concept. At the time of writing, less than a handful of studies (Wright et al., 2020; Maughan, MacFarlane & Swinton, 2021) have aimed to understand the use of dRPE within youth soccer. Wright et al. (2020) reported meaningful differences in differential session ratings of perceived exertion (sRPE-B and sRPE-L) when distinct sessional differences were present (e.g., resistance and fitness training). In a fitness session sRPE-B was very likely to be harder than sRPE-L (*ES = 1.20*) (Wright et al., 2020). However, in a resistance session sRPE-L was likely to be harder than sRPE-B (*ES = 0.84*) (Wright et al., 2020). Despite the meaningful differences reported, when dRPE (sRPE, sRPE-B & sRPE-L) was taken for match-play and training sessions, most differences between the facets of dRPE were a majority trivial (*ES = 0.18-0.56*) (Wright et al., 2020). The results therefore suggest that dRPE may not be worthwhile within youth soccer training or match-play. Maughan et al. (2021) reported strong correlations between sRPE, sRPE-B and sRPE-L and external load variables, therefore suggesting they are indeed measuring what they are intended to measure. However, as with the previous work of Wright et al. (2020), it is suggested that sRPE, sRPE-B and sRPE-L are not distinct and within the youth population provide practitioners with the same information (Maughan et al., 2021). Further research into the usefulness of dRPE within the youth population is required as the previous two studies have utilised differing youth populations. Wright et al. (2020) used thirty-three female soccer players from an FA regional talent club (15 ± 1 years), whereas Maughan et al. (2021) used twenty male professional soccer players (17.4 ± 1.3 years).

2.0 Literature review

2.1 Growth & maturation

It is well documented that one's chronological age, maturity status, body height and mass contribute significantly to the inter-variation of physical capacities (e.g., strength, power, aerobic capacity) (Malina, Bouchard & Bar-Or, 2004a; Vaeyens et al., 2006). Biological maturation refers to the progress toward the adult or mature state in terms of status, tempo, and timing (Malina, Bouchard & Bar-Or, 2004a; Malina, Rogol, Cumming, Silva & Figueiredo, 2015). Status refers to the state of maturation at the time of observation (e.g., pre/post pubertal), timing is the age at which maturational occurrences take place, for example age at peak height velocity (Cumming et al., 2017a). Tempo is the speed at which a person matures, as children of the same age may mature at vastly different rates (Cumming et al., 2017a). Youth athletes are very often grouped by their chronological age, for training and competition purposes (Baxter-Jones, 1995). However, children of the same chronological age can often vary substantially in status (maturation status at time of observation) and timing (chronological age when specific maturation events occur) of maturity, with some individuals maturing in advance or delay of their peers (Malina, Rogol, Cumming, Silva & Figueiredo, 2015).Within chronological age groups, boys who are farther biologically advanced are found to perform better in aerobic, speed and jumps tests, on average, when compared to those individuals who are later maturing (Malina, Eisenmann, Cumming, Ribeiro & Aroso, 2004b). Malina et al. (2004b) categorised individual's growth status based upon pubic hair development from 1-5, with 5 being the most developed. Players in stages 2-5 all performed significantly better ($p < 0.05$) in an aerobic capacity test compared to those in stage 1. In a 30m sprint test, players in stages 4 and 5 performed significantly better ($p < 0.05$) than those in stages 1 and 2, with no difference in the times between stages 1 and 3 and stages 3 and 5. The vertical jump test did not show a consistent trend as players in stage 4 performed significantly better ($p < 0.05$) than players in stages 2 and 3 (Malina et al., 2004b). Performance differences between contrasting maturity statuses are most prevalent between the ages of 13-15years (Malina et al., 2004b). Malina et al. (2004b) concluded that biological maturity is a significant influence in the functional capacity of adolescent soccer players. Indeed, it has been reported that maturity status impacts upon an individual's physical capacities, however it is thought to impact upon the variance of sport-specific skills (passing, dribbling, ball control, shooting) significantly less (Malina et al., 2005; Vaeyens et al., 2006).

2.1.1 Maturation-selection Hypothesis

Previously it has been thought that relatively older players within age groups are more likely to be selected into talent identification programmes, exposed to more expert coaching, and afforded greater match-play minutes (Vaeyens, Philippaerts & Malina, 2005), as an outcome of having greater anthropometric and physical characteristics (Towlson et al., 2017). This is referred to as the maturation-selection hypothesis (Cobley, Baker, Wattie & McKenna, 2009). This was believed to be an issue for the less biologically mature player as it may have resulted in their premature de-selection (Lovell et al., 2015). Previously, research in youth soccer has led to the suggestion that early maturing players are preferentially selected whilst the later maturing players are de-selected (Malina et al., 2000; Malina, 2003; Williams & Reilly, 2000). There is growing concern between practitioners that skilled, but biologically delayed, soccer players are being lost in the early stages of development (Lovell et al., 2015). Despite the maturation-selection hypothesis being discussed in previous work, very little has been done to better understand or address the issue by exploring the physical and anthropometrical advantages afforded to relatively older players (Malina, Ribeiro, Aroso & Cumming, 2007a; Carling et al., 2009). The aforementioned hypothesis may also justify players' early positional assignments within talent identification programmes; an environment which demands high levels of performance and competition (Hirose, 2009). However, more contemporary research has found this not to be the case as research into academy soccer has found that practitioners do not believe enhanced maturity to be a desirable factor in the selection of talented individuals into talent programmes (Towlson, Cope, Perry, Court & Levett, 2019; Towlson, 2021). To further extinguish the claims that relatively older players in the age group are more likely to be selected, Hill, Scott, Malina, McGee and Cumming (2020) reported no association between relative age and maturation with age groups.

2.1.2 Bio-Banding

The idea of 'bio-banding' originated in the early 20th century in the context of child labour. Crampton (1908) proposed the use of 'physiological age', indicated by secondary sex characteristics (e.g., pubic hair) as a determinant of readiness to work. The proposal of 'anatomic age' with the use of radiographic assessment of the carpal bones, demonstrates an early practice of skeletal maturation estimation for grouping children in sports and school (Rotch, 1909). Krogman (1959) illuminated an overrepresentation of early maturing boys in the 1957 Baseball Little League World Series which lead to the suggestion of utilising maturity estimation assessments for determining player eligibility and the evaluation of athletic performance. The process of grouping athletes in terms of age and weight has been witnessed throughout a number of combat sports (e.g., Judo, Boxing, Taekwondo and Wrestling). In combat sports extreme mismatches in size are considered to endanger athletes whilst holding competitive equity implications (Albuquerque, Fukuda, Costa, Lopes & Franchini, 2016).

The phrase bio-banding refers to periodically grouping players based upon maturity status rather than chronological age, which allows for the evaluation of players based on maturity status (Cumming et al., 2017a). It is suggested that individual differences in growth and maturation may enhance the risk of injury to those players substantially less mature than their more mature counterparts (Kreipe & Gewanter, 1985; Malina, 2009). Bio-banding may facilitate development in both early and late maturing players by offering them a different learning environment and challenges than traditional chronological age groupings (Bradley et al., 2019). Bio-banding has been shown to represent a greater physical challenge to early maturing players (Cumming et al., 2017b; Reeves et al., 2018). Abbott et al. (2019) reported that early maturing players reported a greater RPE in maturity matched bio-banded competition (7.5 ± 0.9 AU), compared to chronological age group competition (6.6 ± 0.5 AU). In maturity matched bio-banded formats, early maturing players are less able to rely on their physical and functional abilities (Malina et al., 2019; Abbott et al., 2019), therefore forcing them to rely more heavily on technical, tactical, and psychological skills (Cumming et al., 2018). On the contrary, later maturing players can display their physical capabilities better and have been found to be involved in a significantly greater number of tackles ($p < 0.01$) in maturity matched bio-banding (7.5 ± 3.4 AU), compared to chronological age competition (4.4 ± 2.7 AU) (Abbott et al., 2019). Towlson et al. (2020b) found that pre-PHV players reported a greater sRPE-Training load (TL) when competing in mis-matched bio-banded SSGs (i.e., pre-PHV vs post-PHV), compared with maturity matched bio-banded SSGs. Early maturing players displayed significantly more short passes, and significantly less dribbles in maturity matched bio-banded competition, compared to chronological age group competition (Abbott et al., 2019). Towlson et al. (2020b) suggested that maturity matched bio-banded SSGs allows for the enhancement of crucial psychological skills, believed to be important in talent identification in pre-PHV players.

The development of psychological skills has been accepted as a crucial point in the growth of talented youth athletes (Gould, Dieffenbach & Moffett, 2002; Savage, Collins & Cruickshank, 2016). In maturity matched bio-banded training, the early maturing players potentially benefit from the mentoring afforded by older peers. Bio-banding provides early maturing players with a greater diversity of learning experiences, essentially presenting them with similar developmental challenges faced by later maturing players in chronological age competition (Cumming et al., 2017b). Bio-banding presents later maturing players opportunity to improve and demonstrate their physical, technical, and psychological attributes (Cumming et al., 2018). Later maturing players, in maturity matched bio-banding, more actively participate in games and are afforded greater opportunity to demonstrate leadership skills (Cumming et al., 2018; Bradley et al., 2019). The results of bio-banding research suggest that bio-banded groups promote a less physical and more technical and tactical style of play (Cumming et al., 2017b). A comparison on technical and physical performance across bio-banded groups and chronologically aged groups revealed twice as much passing and dribbling in the maturity-matched bio-banded format (Thomas, Oliver, Kelly & Knapman, 2017) Thomas et al. (2017) utilised eight 20-minute matches across two pitch sizes, with the first and fourth games bio-banded and the second and third chronological aged (U13-14). Maturity matched bio-banded competition appears to allow for a greater technical and tactical challenge for players (Romann, Ludin & Born, 2020). By separating players into maturity-matched groups it allows coaches and scouts the opportunity to evaluate early and late maturing players in scenarios where physical differences are less pronounced (Cumming et al., 2018).

Despite the many positives associated with bio-banding, bio-banding often fails to consider psychological and technical skills (Cumming et al., 2017a). For example, an early maturing individual may be discouraged from competing with chronologically older individuals due to detriment of technical ability, in comparison, which may lead to a negative learning experience (Lloyd & Oliver, 2012; Lloyd, Oliver, Faigenbaum, Myer & De Ste Croix, 2014). Similarly, an individual who is late maturing may not benefit from performing with those chronologically younger if they are already succeeding within their own age group (Cumming et al., 2017a). It is suggested that to make the most of bio-banding, when grouping players into their bio-banded squads, each individual's psychological and technical skills should be considered as well as their maturity status (Cumming et al., 2017a).

2.2 Maturation estimations

Individual differences in the timing of maturation impact both physical and psychosocial development (Baxter-Jones, 2009; Malina et al., 2004a; Sherar, Cumming, Eisenmann, Baxter-Jones & Malina, 2010), please refer back to *2.1 Growth & Maturation* for the impact of individual differences within chronological age groups. Physical performance is linked to biological maturation during male adolescence (Philippaerts et al., 2006). The link is more prominent when comparing individuals of contrasting maturity (e.g., early vs late maturing) (Philippaerts et al., 2006). It is generally accepted that early maturing individuals outperform their later maturing peers in physical tests (Beunen et al., 1988; Malina et al., 2004b). Biological maturation can be calculated utilising several methods, which range from anthropometric measurements to the radiography of the left wrist. The use of non-invasive methods to estimate one's biological age are becoming increasingly common, due to the known proportionality in differences in leg and trunk length growth (Mirwald, Baxter-Jones, Bailey & Beunen, 2002).

2.2.1 Peak Height Velocity

Age at peak height velocity (aPHV) is the most commonly used indicator of maturity in longitudinal studies of adolescence (Malina & Bouchard, 1991). Peak height velocity (PHV) is the period in which the peak attainment of growth occurs (Fransen et al., 2017) and offers an accurate benchmark of the maximum growth during adolescence (Mirwald et al., 2002). Biological age differences between individuals are particularly apparent around PHV and reflects large variations between the timing and tempo of growth among individuals (Malina et al., 2004a). As an adolescent's growth spurt varies in terms of timing, tempo and duration, PHV is used, as oppose to chronological age, to describe changes in size, body composition and performance in relation to an individual's growth spurt (Beunen et al., 1988; Malina et al., 2004a). Data regarding aPHV among youth soccer players is limited (Philippaerts et al., 2006), however studies of Welsh (Bell, 1993) and Danish (Froberg, Anderson & Lammert, 1991) youth soccer players identified identical aPHV (14.2 ± 0.9 years). This value falls between the range of estimated aPHV for European males (13.8 - 14.2 years; Malina et al., 2004a). Data for the general population of adolescent males suggest that an individual's maximal running speed achieves maximal growth prior to the onset of PHV, whilst maximal aerobic power output is attained during one's PHV, however, an individual's maximal strength and power is only achieved after PHV (Beunen & Malina, 1988; Malina et al., 2004a), this is all beneficial in order to inform a coaches practice.

2.2.2 Mirwald et al (2002) method

Non-invasive methods, for the calculation of biological age, arose from the known difference in timing between height, sitting height and leg length (Fransen et al., 2017). It was argued by Mirwald et al. (2002) that the changing relationship between these variables over time provides a good base for the prediction of aPHV. The equation can be used to predict years from PHV, terming this biological age a 'maturity offset' (years from aPHV). An individual's maturity offset can be calculated by using measures of stature, body mass, leg length, sitting height and chronological age (Mirwald et al., 2002). In the original study by Mirwald et al. (2002) prediction equations were developed using a sample of Canadian children (113 boys and 115 girls) from 1991-1997. The children were between 4 years prior to and 3 years post PHV, with the sample cross-validated against a combined sample of Canadian (71 boys and 40 girls; measured from 1964-1973) and Flemish children (50 boys and 48 girls; measured between 1985-1999). It was suggested that the maturity offset prediction is only applicable in youths between 10-18 years of age (Mirwald et al., 2002). Malina and Koziel (2014) attempted to validate the method with a sample of Polish males between 8-18 years of age. The results displayed an inconsistency between predicted and observed aPHV, it was recorded that the value was underestimated in younger age groups and overestimated in older age groups. The findings of Malina and Koziel (2014) were consistent with the limitations of the equation highlighted in the original study. Mills, Baker, Pacey, Wollin and Drew (2017) demonstrated the lack of validity in the equation by concluding that equation-based methods tend to overestimate the timing of PHV when applied in the period immediately before PHV. The original prediction equation (Mirwald et al., 2002) has considerable limitations, especially for those individuals further removed from their aPHV (Malina & Koziel, 2014), and therefore caution must be exercised whilst utilising these prediction equations (Fransen et al., 2017). However, despite the obvious limitations, the use of the aPHV prediction equation has been widespread throughout youth sports (Vandendriessche et al., 2012; Deprez et al., 2013). The use is unsurprising considering the method is practical and non-invasive, however the potential for inaccurate predictions limits its usability and warrants an enhanced equation (Fransen et al., 2017).

2.2.3 Fransen et al (2017) method

A major limitation of the Mirwald et al (2002) equation was the further removed an individual was from their aPHV the greater the degree of inaccuracy in the calculation (Mirwald et al., 2002; Malina & Koziel, 2014; Moore et al., 2015). The increase in error in the extremities of the distribution may be due to a linear assessment of a very non-linear biological process, such as somatic growth during the adolescent growth spurt (Rogol, Clark & Roemmich, 2000). Therefore, Fransen et al. (2017) aimed to improve the accuracy of the original Mirwald et al. (2002) maturity offset prediction equation. A new equation was developed for the prediction of aPHV from anthropometric measures fitting a non-linear relationship between anthropometric predictors and a maturity ratio (Chronological age/aPHV). Maturity ratio is defined as the difference between an individual's chronological age and aPHV (Fransen et al., 2017). It was hypothesised that the new equation would yield similar prediction accuracy, however, would offer a more valid prediction for those further removed from aPHV. It was also expected that the new equation could be validated in an external sample of youth soccer players, if so, consolidating the use of the new equation in male youth athletes (Fransen et al., 2017). The study of Fransen et al. (2017) was comprised of two data sets (dataset 1, new equation using the original dataset Baxter-Jones, Faulkner, Forwood, Mirwald & Bailey, 2011; dataset 2, new equation using a new dataset of Belgian soccer players). Dataset 1 involved the use of 251 Canadian boys (n=115) and girls (n=136) from 2 separate elementary schools, with the measurements taken between 1991-1993 (Baxter-Jones et al., 2011). Dataset 2 involved 1330 elite male youth soccer players from Belgian soccer academies. Data were collected longitudinally, during the same month each year over a 6-year period. In both dataset's anthropometric measures (stature, sitting height, leg length, body mass) and a decimal chronological age, in years, were gathered as per the details outlined by (Ross & Marfell-Jones, 1991). Fransen et al. (2017) preferred the use of maturity ratio over maturity offset. The use of maturity ratio is suitable as adolescents move into adulthood and their rate of growth decreases. Fransen et al. (2017) found that the best fit equation, for the estimation of a maturity ratio, was:

Maturity ratio = 6.986547255416 +(0.115802846632 x Chronological age) +(0.001450825199 x Chronological age (2)) +(0.004518400406 x Body mass) -(0.000034086447 x Body mass (2)) -(0.151951447289 x Stature) +(0.000932836659 x Stature (2)) -(0.000001656585 x Stature (3)) +(0.032198263733 x Leg length) -(0.000269025264 x Leg length (2)) -(0.000760897942 x [Stature x Chronological age]).

The results from Fransen et al. (2017) have resulted in an updated equation that better accounts for the prediction error for those individuals further removed from their aPHV. Somatic growth is not a linear process, and it has been revealed that growth peaks in early infancy and during the adolescent growth spurt (Malina et al., 2004b).

The research model by Fransen et al. (2017) was a nonlinear relationship between anthropometric measures and a response variable (maturity ratio). While the original prediction model was merely linear, the use of a polynomial equation, consisting of several terms, allows for a more accurate representation of the nonlinear relationship between anthropometrical measures and maturity offset (Fransen et al., 2017). The use of maturity ratio (Chronological age/aPHV), as oppose to maturity offset (Chronological age – aPHV) appeared to offer a better fit as a model in both the general (dataset 1) and athletic (dataset 2) samples, even when the difference between aPHV and chronological age was large. The prediction of a ratio resulted in a superior prediction of aPHV over the use of linear models in both datasets. The findings of Fransen et al. (2017) illustrate that the updated equation provides a more reliable estimation of aPHV compared to the original equation (Mirwald et al., 2002), even when age is widely dispersed from aPHV.

2.2.4 Khamis & Roche (1994) method

One's mature height can be estimated by gathering an individual's decimal age, stature, body mass and their parental mid-height, which is simply the combined average stature of their biological parents (Khamis & Roche, 1994). By utilising the Khamis-Roche method two distinct variables can be ascertained; predicted adult height (Khamis-Roche, 1994) and percentage of their estimated adult stature attainment (%EASA) (Roche, Tyleshevski & Rodgers, 1983). The latter of which is becoming increasingly common in the indication of maturity status in youth athletes (Malina, 2014, 2017). EASA defines early maturing as [>96.1%EASA] and late maturing as [<84.9%EASA]. When viewing youth of the same chronological age, individuals who are closer to their mature adult stature are further biologically developed (Gillison, Cumming, Standage, Barnaby & Katzmarzyk, 2017). It has been noted the median error between predicted and actual height is 2.2cm in males and 1.7cm in females, between the ages of 4 and 18 (Khamis & Roche, 1994). Whilst utilising the Khamis-Roche method (Khamis & Roche, 1994) within the field, parental mid-height is often self-reported and it is common for inconsistencies and errors to occur when parents self-report height, hence a correction calculation was employed to adjust any over-estimated heights (Epstein, Valoski, Kalarchain & McCurley, 1995). The calculation was based upon the measured and self-reported heights of adults in the US (Epstein et al., 1995). The estimation calculation was created from over 1000 measured statures (Epstein et al., 1995). The need for an adjustment calculation is due to the fact self-reported height is often over-estimated and mass is often under-estimated (Bowman & DeLuca, 1992).

The Khamis-Roche method has been widely used with both US and British youth populations (Cumming, Battista, Standage, Ewing, & Malina, 2006; Malina, Morano, Barron, Miller, & Cumming, 2005; Sweet, Dompier, Stoneberg, & Ragan, 2002). The validity of the method has been tested against an established gauge of biological maturity (skeletal age) in an American youth population (Malina et al., 2007a; Malina, Dompier, Powell, Baron & Moore, 2007c), Portuguese soccer players (Malina, Silva, Figueiredo, Carling, & Beunen, 2012) and in a British populace (Cumming, Standage, Gillison & Malina, 2008; Cumming et al., 2011; Smart et al., 2012). A moderate association between %EASA and skeletal age, the gold standard clinical indicator in biological maturity, has been declared (Malina et al., 2007c). Furthermore, US, British and Portuguese youth populations (Cumming, Battista, Standage, Ewing & Malina, 2006; Malina, Morano, Barron, Miller & Cumming, 2005; Sweet, Dompier, Stoneberg & Ragan, 2002) have publicised levels of concurrent and predictive validity in the Khamis-Roche estimation method (Cumming et al., 2018).

Fragoso, Teles, Albuquerque, Barrigas and Massuca (2014) aimed to validate a non-invasive method (Khamis & Roche, 1994) of obtaining predicted adult statue and %EASA, using the Tanner-Whitehouse 3 (TW3) (Tanner, Healy, Goldstein & Cameron, 2001) skeletal age method as a reference. It was reported by Fragoso et al. (2014) the Khamis-Roche method and TW3 revealed strong general agreement for predicted adult stature and %EASA. However, the Khamis-Roche method has been found to underestimate predicted adult stature in later maturing players and overestimate predicted adult stature in earlier maturing players (Malina, Silva, Figueiredo, Carling & Beunen, 2012; Fragoso et al., 2014).

2.3 Skeletal maturity

Skeletal maturity is the single best way to assess one's maturity, however this technique requires specialist equipment as well as the unnecessary risk to enhanced radiation (Mirwald et al., 2002). Skeletal maturation is evident within recognisable changes in appearance of the skeleton during childhood (Zerin & Hernandez, 1991). Such changes include the specific alterations of bone contours and the timing and sequence of the ultimate closure of growth plates (Zerin & Hernandez, 1991). Skeletal maturity can be assessed, via a radiograph, by comparing the x-ray with a standardised population of children at different periods of their progress towards the mature state (Zerin & Hernandez, 1991). The most common area utilised for radiographic assessment is the left hand and wrist. The hand and wrist are the focus of skeletal maturity evaluation due to their easy accessibility, location and the number of bones in a dense area (therefore limiting the amount of radiation exposure) (Cox, 1997). There are three main methods for the assessment of skeletal maturity: The Greulich-Pyle Atlas method (Greulich &

Pyle, 1950), Tanner-Whitehouse (Tanner & Whitehouse, 1959) and The Fels Method (Roche, Chumlea & Thissen, 1988).

2.3.1 Greulich-Pyle

The Greulich-Pyle protocol involves matching the given hand-wrist radiograph with the one most closely matched from the Greulich-Pyle atlas reference, to estimate one's skeletal age (Carling, Le Gall & Malina, 2012). Skeletal age is an indicator of biological maturity status (Le Gall et al. 2010), when assessing skeletal age, a positive score illustrates skeletal age is in advance of chronological age, whereas a negative score indicates skeletal age is behind chronological age (Malina et al. 2000). The level of development is assessed in several ways; the size of the radial and ulnar epiphyses relative to their respective diaphysis, size of the sesamoid, the extent of epiphyseal (the end of a long bone) capping in the metacarpals and phalanges, and the extent of epiphysis to diaphysis fusion in all of these bones (Dembetembe & Morris, 2012). The atlas is based upon a population of American children from whom were thought to be originally of North European descent and from an above average educational and economic background (Greulich & Pyle, 1959). The method has been shown to have sound levels of reliability and validity (Haiter-Netoa, Kuritab, Menezesc & Casanova, 2006). The Greulich-Pyle method is the most frequently used skeletal maturity assessment method in the United States of America (Zerin & Hernandez, 1991). The Greulich-Pyle method is used internationally as a standard method for obtaining skeletal age (Le Gall et al., 2010; Tsehay, Afework & Mesifin, 2017).

Despite the common use of the Greulich-Pyle method worldwide, the applicability of the reference sample to the worldwide population is often questioned (Tsehay, Afework & Mesifin, 2017). The Greulich-Pyle method is not an appropriate method for estimating skeletal age in Turkish boys, as they may differ in skeletal tempo compared to the original population in the Greulich-Pyle atlas (Koc, Karaoglanoglu, Erdogan, Kosecik & Cesur, 2001). Similar suggestions have also been made in Ethiopian (Tsehay, Afework & Mesifin, 2017) and South African (Dembetembe & Morris, 2012) populations. In the South African population, the Greulich-Pyle method underestimated skeletal age in ~74% of the population and overestimated in ~26% of the population (Dembetembe & Morris, 2012). Dembetembe and Morris (2012) also remarked that in South African males' skeletal maturity, categorised as the complete epiphyseal fusion, occurred 2.1 years later than Greulich-Pyle's estimate of 19 years. The Greulich-Pyle method displayed high precision and low accuracy and was therefore not appropriate to the African male population (Dembetembe & Morris, 2012). There is however support for the use of the Greulich-Pyle method, albeit with a set of recommendations, within a population of Scottish males and females (0-21 years) (Hackamn & Black, 2013). Hackman and Black (2013) argued the Greulich-Pyle method was applicable for the modern population, however, must be revised to consider the potential for over- or under- ageing, as they found. The population often under-estimated the age of male's pre-puberty (13 years) and over-estimated post puberty (Hackman & Black, 2013). Over- and under- estimating has also been reported in a number of other studies whilst using the Greulich-Pyle method (Ontell, Ivanovic, Ablin & Barlow, 1996; Koc et al., 2001; Zafar, Nadeem, Husen & Ahmad, 2010). The onset or progress of one's development may be hugely diverse across various populations as it may be affected by several factors including socioeconomic, racial, genetic, and environmental factors (Marshal & Tanner, 1970; Wheeler, 1991). It has been suggested, in order to enhance the Greulich-Pyle method, a number of modifications may be required on a population-to-population bases (Koc et al., 2001). However, as the current method stands, high levels of both intra- and inter-observer reliability have been found (Ontell et al., 1996; Zafar et al., 2010; Hackamn & Black, 2013).

2.3.2 Tanner-Whitehouse

The Greulich-Pyle and Fels methods were both developed using a population of middle-class American children, whereas the Tanner-Whitehouse method used healthy British children (Malina, 2011; Malina, 2017). There have been two revisions of the original method, Tanner-Whitehouse 2 (TW2) and TW3 (Malina et al., 2018). The original method provided skeletal age based on maturity indicators for 20 bones: the radius, ulna, eleven metacarpals and phalanges of digits 1, 3 and 5 and seven carpals, excluding the pisiform (Tanner, Whitehouse & Healy, 1962). The first amendment (TW2) (Tanner et al., 1975), did not modify the specific maturity indicators. The final stages of the ulna, radius and seven carpals were removed, as they were deemed too difficult to rate, the assigned scores were therefore altered (Malina et al., 2018). The revision offered three skeletal ages based upon, the 20 bones (TW2 20 Bone Skeletal age), 7 carpals (TW2 Carpal Skeletal age) and the radius, ulna, and short bones (TW2 RUS Skeletal age) (Malina et al., 2018). The TW2 method is a scoring method with the maturity level of each bone being categorised into a stage (Stage A to H to I) (Satoh, 2015). Each stage is then replaced by a score, the total score is then calculated and transferred into a bone age (skeletal age) (Satoh, 2015). The second revision (TW3) (Tanner, Oshman, Babbage & Healy, 1997; Tanner et al., 2001) preserved RUS skeletal age (TW3 RUS Skeletal age) and carpal skeletal age (TW3 Carpal Skeletal age), however it eradicated the 20-bone skeletal age. Once again, the criteria for maturity indicators were not modified (Malina et al., 2018). The table for converting the sum of maturity scores to a skeletal age was only modified for the radius, ulna, and short bone, this was not for the

7 carpal bones to a skeletal age (Malina et al., 2018). The reference values used in Tanner-Whitehouse, TW2 and TW3 carpal skeletal age were gathered from a population of British children, however reference values in TW3 RUS skeletal age were gathered from an amalgam of Belgian, Italian, Spanish, Argentine, Japanese and American children and adolescents (Malina et al., 2018). Standardised Tanner-Whitehouse methods have been reported across various countries, and these methods have changed the relationship between the total bone maturity score and bone age, making the relationship appropriate for each ethnic group (Beunen et al., 1990; Murata, 1993; Tanner et al., 1997). Whilst employing the Tanner-Whitehouse method, Malina (1969) reported a practically identical age relationship and progress in skeletal maturity between African American and Caucasian males however noted greater variability within girls. The standard deviation of bone age using the TW2 RUS method was ~1 year, from 5-14 years in girls, 5-16 years in boys (Tanner et al., 1983).

The TW2 method is thought to produce higher levels of reproducibility, compared to the Greulich-Pyle atlas method, due to a more objective scoring system used in the TW2 method (Satoh, 2015). Intra-observer variation was greater for Greulich-Pyle compared to TW2 (Bull, Edwards, Fry & Hughes, 1999). However, the TW2 method required a greater time requirement (7.9 minutes), compared to the Greulich-Pyle method (1.4 minutes) (King et al., 1994). The TW3 RUS and Fels methods yield different skeletal ages in elite youth soccer players, with a significantly greater number of 15-year-old boys being classified as skeletally mature with the TW3 RUS method compared to the Fels method (Malina, Chamorro, Serratosa & Morate, 2007). Just as the Greulich-Pyle method, the Tanner-Whitehouse method has been utilised to verify chronological age within youth sport competitions (Malina, 2011). Maturity assessments amongst male youth soccer players has utilised skeletal age through the TW2 20 bone, TW2 RUS, Greulich-Pyle and Fels, and TW3 RUS, albeit to a lesser extent (Malina et al., 2018). TW3 RUS skeletal ages were lower than Fels skeletal ages in a sample of elite Spanish players (Malina et al., 2007b). Among elite Swiss players, 21% were classified as late maturing and 20% were classified as early maturing after utilising TW3 skeletal ages (Romann, Javet & Fuchslocher, 2017), these results contrasted maturity classifications of 14-year-old soccer players using TW2, Fels and Greulich-Pyle skeletal ages (Malina, 2011; Malina, Silva & Figueiredo, 2013).

2.3.3 The Fels Method

The Fels method provides an estimated skeletal age and its associated standard error based upon the assessment of the bones in the hand-wrist (Nahhnas, Sherwood, Chumlea & Duren, 2013). This is accompanied by examining the distribution of chronological age among children within the reference sample with skeletal maturity similar to the appropriate reference group (Roche, 1992). In the Fels method the reference group applies to the participants within the Fels Longitudinal Study (Roche, 1992). The reference group in the longitudinal study was comprised of 677 Caucasian children (355 boys, 322 girls). The Fels method measures 98 skeletal maturity indicators (58 binary, 27 ordinal and 13 continuous measures) from a hand-wrist radiograph, with only 20-66 indicators being assessed at any one time (Nahhnas, Sherwood, Chumlea & Duren, 2013). The Fels method uses set criteria for each bone and ratios of linear measurements of epiphyseal and metaphyseal (the narrow portion of a long bone containing the growth plate) widths (Figueiredo, Gonçalves, & Malina, 2009b). Ratings are entered into a specialised computer programme (Felshw 1.0 Software) to calculate skeletal age and its standard error of estimation (Figueiredo et al., 2009). A comparison among hand-wrist skeletal assessment methods found the Fels method to be the most appropriate method for the children of the United States, at the time of publication, when compared with the Greulich-Pyle and Tanner-Whitehouse methods (Chumlea, Roche & Thissen, 1989).

2.4 Sexual maturity

The assessment of sexual maturation is based upon the development of secondary sex characteristics (Beunen, Rogol & Malina, 2006). During puberty, boys of the same chronological age can be grouped by stage of genital development or pubic hair growth providing an estimate of variation in body size associated with maturity status within an age group (Malina, 2003). Such comparisons are only applicable among youth of the same chronological age, or within a narrow age range (Malina, 2003). It has been suggested that indicators of sexual maturity are only useful during puberty (Malina, 2003). Sexual maturity is often estimated through a method proposed by Tanner (1962), by stage of genital development and/or pubic hair growth. Stages range from 1 (pre-pubertal) to 5 (mature). It is important to note however, the stages of development (genital development and pubic hair growth) are not interchangeable (Beunen et al., 2006), for example stage 2 pubic hair growth is non equivalent to stage 2 genital development. The stages proposed by Tanner (1962) are as follows; stage 1 indicates the absence of development, stage 2 is the preliminary development of each characteristic, stages 3- and 4-mark progress in maturation and stage 5 is the mature adult state.

Secondary sex characteristics are reasonably easy to determine (Beunen et al., 2006), however a major drawback is the clinical assessment is invasive, as it involves a trained clinician observing the genital area (Beunen et al., 2006). The stages of development are also arbitrary and discrete (Beunen et al., 2006). The use of secondary sex characteristics is associated with sanctions in some cultures (Beunen et al., 2006). However, one way to overcome the invasiveness associated with this method is through self-assessment protocols, using Tanner staging photographs (Tanner, 1962). The accuracy of self-assessment of sexual development in adolescents is still unclear (Leone & Comtois, 2007). Some studies have reported good levels of agreement between self-assessment and that of a trained physician (Neinstein, 1982; Wacharasindhu, Pri-Ngam & Kongchnrak, 2000), whereas other papers have reported diminished results (Shlossberger, Turner & Irwin, 1992; Hergenroeder, Hill, Wong, Sangi-Haghpeykar & Taylor, 1999). Leone and Comtois (2007) reported that self-assessment is a valid and reliable method to assess sexual maturity in elite adolescent athletes.

2.5 Ratings of Perceived Exertion

The perception of effort is a cognitive feeling of work from voluntary actions (Preston & Wagner, 2009). Effort may describe a particular feeling of energy being exerted (Preston & Wagner, 2009). The perception of effort is multidimensional and is influenced by a number of physiological and psychological factors (Morgan, 1994). For example, the personality trait, extrovert, has been inversely correlated to perceived exertion at power outputs 150W (-0.62), 200W (-0.69) and 250W (0.71) (Morgan, 1994). However, at power outputs 50W and 100W RPE and extroversion were not correlated (Morgan, 1994). Perceived exertion is a method of determining one's intensity effort, stress or discomfort experienced during exercise (Noble & Robertson, 1996). The concept of perceived exertion was first introduced in the latter years of the 1950's by Gunnar Borg (Borg, 1998). The terms fatigue and perceived exertion are very similar when describing heavy physical exercise, however several variances between fatigue and perception of exertion do exist (Borg, 1998). Firstly, fatigue refers to a high level of tiredness or exhaustion, which therefore leads to diminished performance levels in an individual (Borg, 1998). On the other hand, perceived exertion, at very high intensities is additionally associated with diminishing performance, however at low to moderate intensity associated with a state of activation, an 'arousal' state that has a positive effect on performance (Borg, 1998). For perceived exertion to be operationally defined it must be coupled with a method of obtaining said parameter (Borg, 1998). A measure of perceived exertion is the "degree of heaviness and strain experienced in physical work as estimated according to a specific method" (Borg, 1998). The definition previously described refers to an overall rating of perceived exertion (RPE), which is dependent upon numerous factors, for example, sensory cues, somatic symptoms, emotional factors (Borg, 1998). In some cases, local sensations of strain dominate over others, and this is termed local RPE with the term local referring to that specific area (e.g., leg RPE, chest RPE, arm RPE etc.) (Borg, 1998). The term chest RPE is used when breathlessness is the overwhelming sensation. Borg (1961b, 1962a) was the first to prescribe the differentiation between perceived exertions. In acute exercise over a short duration (seconds), leg sensations dominate, however for heavy exercise over several minutes chest exertion may dominate due to the work on the cardiopulmonary system (Borg, 1998). Ekblom and Goldbarg (1971) used the terms 'local' and 'central' perceived exertion to differentiate the divisions, however the terms may be regarded as misleading as the term 'central' is often used to describe the central nervous system in physiology.

Ratings of perceived exertion is commonly used to calculate internal training load within a training session or following competition (Fanchini et al., 2016). Session RPE (sRPE) denotes a single average rating of intensity for the entire session, rather than at selected moment (Foster et al., 2001). Session ratings of perceived exertion is a well-established and validated method of quantifying an individual's internal training load in a given session (Foster et al., 2001). sRPE is calculated as a product of an athlete's perceived intensity and the duration of the session (Haddad et al., 2013; Fanchini et al., 2016). Initially the method of sRPE was endorsed within endurance sports (Foster et al., 2001), however, more recently has been validated as a measure of internal load within soccer (Impellizzeri, Rampinini, Coutts, Sassi & Marcora, 2004; Impellizzeri, Rampinini & Marcora, 2005). Session RPE can provide valuable training load information to practitioners throughout the season and can be of great use in both individual (Haddad et al., 2011) and team sport environments (Coutts, Rampinini, Marocra, Castagna & Impellizzeri, 2009; Manzi et al., 2010). There are a multitude of scales created and utilised by various authors which have been used to obtain an individuals' RPE, the most common of which will now be discussed.

2.6 The Borg RPE scale

The Borg RPE scale known today, was not the first attempt Gunnar Borg made at producing a category scale, initially, the process began with a 7-point rating scale where all points were acquainted with a verbal expression (e.g., 1-very very light; 7- very very hard) (Borg, 1998). A high correlation between given ratings and heart rate (HR) was reported whilst using the 7-point scale, however the scale was deemed to be too small to differentiate entirely between a wide range of different intensities (Borg, 1998). It is commonly accepted that an individual's heart rate is a good general indicator of physical strain (Noble & Robertson, 1996). Gunnar Borg reasoned a perceptual scale, that produced results closely aligned with pulse rate, would provide sufficient support for perceived exertion as a subjective indicator of physical strain (Noble & Robertson, 1996). Therefore, an increased scale was produced with the numbers ranging from 1-

21, in a 21-point rating scale (Borg, 1961b). The scale was used predominantly in Sweden during the 1960's, however a drawback with the scale was that there was no linear increase that agreed with the physiological demands (Borg 1962a, 1970b). The Borg RPE scale was constructed after the knowledge gained from the previous two scales. The results from the 21-point scale showed that a rating of 17 roughly corresponded with a HR of 170 beats.min^{-1} in a normal healthy group of men and women on a cycle ergometer, with increased workload every sixth minute (Borg, 1998). However, there was a nonlinear relationship between ratings and workloads that meant it would be difficult to make interpolations and extrapolations between HR-rating and workload rating (Borg, 1998). Therefore, to overcome the problem, ratings were placed to grow linearly with workload, which in turn simplifies the comparisons between work rate and HR. Borg designed a new 15-point scale that aligned approximately with a HR range of a healthy population 60-200 beats.min^{-1}, with the new digits of the scale associated with a specific HR in a linear fashion (HR=RPEx10), the new scale ranged from 6-20 (Nobel & Robertson, 1996). Number 6 was chosen as the start point of the scale as a low resting HR estimate of adults is 60 (6x10=60) (Borg, 1998). Every odd number on the scale was given a verbal phrase (7, very very light; 19, very very hard). A start point of 6, as opposed to 0, illustrates the scale is not a ratio scale due to the absence of an absolute zero (Borg, 1998). The RPE scale was constructed to give a moderately linear increase between workload and HR (and VO2) during cycling (Borg, 1998).

A minor change to the scale was made in the 1980's as the term 'No exertion at all' was anchored with number 6, the term 'very very light' was replaced with 'extremely light' and moved up half a step meaning it was now housed between 7 & 8, the term 'fairly light' at point 11 was changed to 'light' and finally 'maximal exertion' was fixed to number 20 (Borg, 1985). The rationale behind the modification of the scale was due to research by Borg and Lindblad (1976) on the interpretation and precision of 37 different verbal cues from 'minimum' to 'almost maximal'. In the study, groups of subjects rated the envisaged intensities based solely upon the verbal expression. Interpretation was rated by the mean and median position on the scale with precision by the relative distribution around the mean (Borg & Lindblad, 1976). The number 20 on the scale refers to an 'absolute maximum', an intensity that most people will never have previously reached in their lives, therefore making it a hypothetical construct (Borg, 1998). According to the definition and instructions of the scale 19 should be the highest intensity that most people have ever experienced (Borg, 1998). When using the scale, correlations have been reported between HR and RPE in a graded exercise test, with results at .94 and .85 for tests on a bike ergometer and treadmill, respectively (Nobel & Robertson, 1996). However, correlations at a single exercise intensity are found to be much lower (Nobel & Robertson, 1996). Lamb and Eston (1997) argued the Borg scale is now accepted to be unsuitable for use with younger children.

2.6.1 The Borg RPE scale reliability

The reliability of subjective ratings of exertion has often been questioned, simply because the term subjective implies something private but also occasionally uncertain (Borg, 1998). A number of parameters may negatively affect the reliability of a scale; estimation of something vague, small range of variation or bad instruction (Borg, 1998). Over a large range of intensities, perceived exertion is simple to describe and categorise (Borg, 1998). In order to identify certain intensity levels subjects may be facilitated by a number of physiological cues (e.g., sweat, heavy breathing) (Borg, 1998). The reliability of the scale was assessed through a test re-test protocol and reliability coefficients were found between 0.71 and 0.91, therefore the scale could well be regarded as a reliable measure of perceived exertion (Noble & Robertson, 1996).

2.6.2 The Borg RPE scale validity

Although validity is a fundamental concept, within psychophysics validity is not recognised as a major problem (Borg, 1998). The assessment of perceived exertion and their validity depend significantly upon the procedure in place to acquire the responses (Borg, 1998). Given a good definition of the attribute to be measured, a reliable method and precise instructions, it is considered that a high validity is guaranteed (Borg, 1998). Validity criteria have consisted of comparisons between perceptual responses in protocols where power output was presented both progressively and at random with correlations between perceived exertion and HR and perceived exertion and energy expenditure. In all cases, the scale was deemed as a valid assessment instrument for perceived exertion (Nobel & Robertson, 1996).

Since its development Borg's 15-point RPE scale has been widely utilised throughout a range of experimental situations (Noble & Robertson, 1996). The scale has been utilised across a vast breadth of research, including; physical training (Ekblom & Goldbarg, 1971), walking and running studies (Noble & Borg, 1972), concentric vs eccentric muscle contractions (Henriksson, Knuttgen & Bonde-Paterson, 1972), temperature (Pandolf, Cafarelli, Noble & Metz, 1972), muscle mass (Sargeant & Davies, 1973), altitude (Horstman, Weiskopf & Robinson, 1979), psychology (Rejeski & Ribisl, 1980), menstruation (Higgs & Robertson, 1981), sleep deprivation (Martin & Gaddis, 1981), gender (Noble, Maresh & Ritchey, 1981), circadian rhythms (Faria & Drummond, 1982), occupational tasks (Asfour, Ayoub, Mital & Bethea 1983) and aging (Miller, Bell, Collins & Hoshizaki, 1985). Growth was another area in which

RPE was utilised, initially with Eston and Williams (1986) in which 30 adolescent boys were tested on a cycle ergometer at three submaximal intervals. The correlation between perceived exertion & power output and perceived exertion & HR were .78 & .74, respectively (Nobel & Robertson, 1996). The values found were similar to that of an adult's test, therefore RPE was considered suitable for use within the adolescent populous (Nobel & Robertson, 1996). Although the list may seem excessive it simply highlights the vast range of uses that RPE can be used for within experimental studies. However, a major limitation is evident with the Borg RPE scale as the prediction of HR has since been proven inadequate in several parameters involving different subjects, exercise modes and environmental conditions (Nobel & Robertson, 1996). Some have also regarded the ratings from 6-20 as confusing, however the scale and the use of the scale have remained largely intact (Nobel & Robertson, 1996). Borg offered a defence claiming the prediction equation was not intended to be taken too literally as HR is affected by age, type of exercise, environment, anxiety and other factors (Borg, 1982b).

2.7 Borg CR-10 Scale

The Borg category-ratio scale (CR-10) is a category scale with ratio properties in the way of verbal expressions anchored as specific numerical points (Borg & Kaijser, 2006). The scale includes nonlinear spacing between verbal indicators of exercise intensity and intensity level (Borg, 1980). The scale increases from 0 to 0.5 to 1 and then in equal steps of 1 up to 10, with a point proceeding 10. To reduce the ceiling effect, a common weakness in perceived exertion scales, the maximal intensity cue was placed outside of the 0-10 range (Borg, 1980). The Borg CR-10 scale is a standard method for the evaluation of perceived effort across a multitude of areas such as training, rehabilitation, and testing (Noble, Borg, Jacobs, Ceci & Kaiser, 1983; Borg, 1985). Despite the scale having 'no ceiling' and the participants being encouraged to use decimal places when giving their RPE, the scale fails offer sufficient rating possibilities to detect small changes of perceived exertion (Pageaux, 2016). The CR-10 scale has been altered since its inception to now include 19 points along the scale from 0-11 (Borg & Borg, 2010), with 11 continued by a point of "absolute maximum' as oppose to "maximal" in the original variation of the scale. The altered scale offers points before 0.5 and after 10 to avoid end effects (Borg & Borg, 2001). Borg also created a further two category-ratio scales to discriminate low intensities easier, the CR12 and CR20 had a number range 1.7 times and 2.9 times greater, respectively, than the CR-10 (Borg & Borg, 2001). The numbers in the CR12 and CR20 were spaced logarithmically (Borg & Borg, 2001). Despite the CR12 and CR20 showing good validity against a series of psychological criteria (Sebald, 1990), they are deemed too difficult to use for ordinary people, hence why the CR-10 became most used (Borg & Borg, 2001).

2.7.1 Borg CR-10 Scale reliability

The CR-10 scale has shown good levels of reliability across various sports and activities in children, adolescents, and adults (Haddad, Padulo & Chamari, 2014b). Reliability has also been revealed in both genders in experienced and inexperienced individuals, highlighting the usefulness of RPE and the CR-10 scale for subjective monitoring (Haddad et al., 2014b). Not only in a sporting context has the CR-10 scale shown reliability, Shariat et al. (2018) established high levels of reliability when using the CR-10 scale in office exercise training. The CR-10 scale is a reliable scale for whole body and isolated movements, only when standardised protocols are correctly followed when obtaining RPE scores (Borg, 1998). Borg and Ohlsson (1975) aimed to assess the retest reliability of the CR-10 scale. In the study participants had to run 800m at three specified running paces. HR and RPE were collected after each run. The participants were also instructed to run 1,200m at two different speeds, the HR and RPE correlations for the two runs were 0.87 and 0.91, respectively. The correlations found showed strong levels of retest reliability in the CR-10 scale. Several other studies also concluded the CR-10 displayed high levels of retest reliability (Borg, Karlsson & Ekelund, 1977; Komi & Karppi, 1977; Ceci & Hassmen, 1991; Lamb, 1995).

Reliability of subjective ratings is often questioned (Borg, 1998). If the question is badly worded or the characteristic to be estimated is too vague then reliability will often be low (Borg, 1998). When translated to another language the scale lack's reliability, this has been shown by Haddad et al. (2014a) when the scale was translated from English to French. The CR-10 scale demonstrated poor levels of reliability in Australian Football when utilised within field testing (Scott, Black, Quinn & Coutts, 2013). It was suggested that when using the scale to obtain sRPE it may not be able to detect small changes in exercise intensity. However, it may be worth bearing in mind this conclusion may be down to sRPE and not the method used to obtain this. Scott et al. (2013) also aimed to establish the levels of reliability in the CR-10 scale for quantifying training intensity in intermittent exercise. The results showed relatively poor levels of reliability, similar results were portrayed by (Rampinini et al., 2007). These studies highlight the collection of RPE may indeed be limited by its reliability in brief bouts of intermittent exercise, which is common in team sports. It was noted by Scott et al. (2013), however, that coefficient variation, a statistical analysis used in their work, may not be suitable for determining the reliability of scales such as the CR-10. It is worth noting however that Scott et al. (2013) found higher levels of reliability at higher intensity exercise. Therefore, suggesting that perception of effort is more reliable the greater the exercise intensity. Similar results were observed by Lamberts, Lemmink, Durandt and Lambert (2004).

2.7.2 Borg CR-10 Scale validity

The CR-10 scale has been validated in a number of studies across various areas (Noble et al., 1983; Borg, 1985; Borg, Ljunggren & Marks, 1985; Neely, Ljunggren, Sylven & Borg, 1992; Shariat et al., 2018). Despite the scale showing good levels of validity in various settings, some have questioned its validity across an array of populations. Foster et al. (2001) first altered the scale by removing the 0.5 rating and discounted the ceiling effect by placing 'maximal' at 10. The wording anchors were also modified to represent American idioms as "Light" became "Easy" and "Strong/Severe" became "Hard" (Foster et al., 2001). Due to the vast array of cultures around the world there is a requirement of mainstream techniques to be altered for all to use, however methodological problems can occur with reference to translation quality, caused by cross-cultural and ethnic validity (Haddad et al., 2013). To simply translate a scale from one language to another is unacceptable (Chen & Boore, 2010). Technical inconsistences can result in, potentially substantial, erroneous conclusions (Haddad et al., 2013). It can be difficult to translate to original items of the CR-10 scale into a culturally comprehensible and relevant form whilst maintaining scale integrity and meaning (Haddad et al., 2013). The translation process, however, can be timely, expensive, and difficult, and without successful implementation, research validity may be compromised (Haddad et al., 2013). Impellizzeri, Rampinini, Coutts, Sassi and Marcora (2004) applied an Italian translation to the modified Foster CR-10 scale (Foster et al., 2001) and found lower correlations in session-RPE – TL compared to HR based-

TL. They suggested greater anaerobic energy contribution in soccer was the reason for the lower correlations. Impellizzeri et al. (2004) disregarded the English to Italian translation as a possible cause as it can affect reliability and validity of the scale. The work of Impellizzeri et al. (2004) also lacks reproducibility due to an absence of an explanation of the Italian translation and a lack of validated Italian translation (Haddad et al., 2013).

Initially the CR-10 scale was designed for and validated with the adult population (Rodríguez-Marroyo & Antoñan, 2015), which means limitations may occur when used with children or adolescents (Marinov, Mandadjieva & Kostianev, 2008). A child's ability to understand RPE scales may affect their scores (Williams, Eston & Furlong, 1994). Haddad et al. (2013) showed sound levels of validity with 10-15-year-old Tae Kwon Do athletes using a modified Borg CR-10 scale, however a weak correlation was reported during high-intensity exercise. Rodríguez-Marroyo and Antoñan (2015) also found no data to support the relationship between sRPE and HR for quantifying TL in youth soccer players (mean ± SD age – 11.4 ± 0.5 years). The results may therefore suggest the CR-10 scale may not be appropriate for use with the youth population.

2.8 Borg CR-100 Scale

The Borg CR-100 (CentiMax) scale was established as a general intensity scale to measure all different perceptions and feelings (Borg & Borg, 2001). The CR-100 scale is a more sophisticated version of the CR-10 scale (Scott et al., 2013). The CR-100 scale was developed to increase the sensitivity of ratings to improve the possibility of detecting small changes in effort perception (Borg, 2007). The CR-100 offers a 1-100 numerical range which, in turn, offers a more finely graded rating system (Borg &

Kaijser, 2006). It is therefore suggested the greater numerical range may offer greater accuracy in ratings (Fanchini et al., 2016). The CR-10 and CR-100 scales have shown comparable psychophysical properties, however the perceptions of effort giving using the CR-100 have shown less clustering around the verbal anchors, compared to the CR-10 (25% vs 37%, respectively), thus suggesting more accurate training load data (Borg & Kaijser, 2006; Fanchini et al., 2017). The CR-10 and CR-100 scales have shown significant correlation in the assessment of breathlessness and leg fatigue (.96 & .95, respectively) (Borg, Borg, Larsson, Letzter & Sundblad, 2010). Borg and Borg (2001) described the rationale behind the verbal anchors, stating that in order to avoid a floor effect, it needs to be possible to go below "Minimum", hence why this verbal anchor was associated with 1.5 on the scale. They also claim that to avoid a ceiling effect, "Absolute Maximum" was placed outside of the numerical range, at greater than 120, adjacent to a dot. "Maximal-Max X" located at 100, on the scale, refers to the greatest ever previously experienced sensation (Borg & Borg, 2001). The "Absolute Maximum" rating falls outside of the numerical range to account for the exceptional occasion that an individual feels as though they have exerted effort greater than they have ever experienced previously (Molander, Olsson, Stenling & Borg, 2013). The CR-100 scale has been offered as an alternative to the CR-10 scale, principally due to its interchangeability and its facility to provide more precise measures of perceived effort than the CR-10 scale (Fanchini et al., 2016).

2.8.1 Borg CR-100 Scale reliability

The CR-100 scale has shown good levels of reliability for the measurement of perceived exertion (Borg, 2007). Borg, Magalhães, Costa and Mörtberg (2019) demonstrated high levels of reliability against a commonly used method of measuring depression in clinical psychology. The CR-100 scale demonstrated poor levels of reliability in Australian Football when utilised within field testing (Scott et al., 2013). It was suggested that when using the scale to obtain sRPE, it may not be able to detect small changes in exercise intensity. However, it may be worth considering this conclusion may be due to the notion of sRPE and not the method used to obtain this.

2.8.2 Borg CR-100 Scale validity

Prior to the validity of the scale being examined, Borg (2007) suggested that due to the interchangeable nature of the CR-100 and the CR-10, an already validated scale, the CR-100 scale could be reasonably assumed to be valid for the measurement of perceived exertion.

The Borg CR-100 scale has, in fact, shown good levels of validity in assessing training load in adolescent soccer players (Naidu et al., 2019). The scale has also demonstrated sound levels of construct validity for the assessment of training load in Australian Football (Scott et al., 2013) and in elite soccer players (Fanchini et al., 2016). To establish construct validity the scale was compared against HR and external load measures (Scott et al., 2013). The scale has also demonstrated good levels of convergent validity when compared with a commonly used scale in the field of clinical psychology to measure depression (Borg et al., 2019). Borg et al. (2019) found the scale identified depressive symptoms as well as the Beck Depression Inventory (BDI; Beck, Steer & Garbin, 1988).

2.9 OMNI scale

It has been expressed that children's RPE scores can be affected by their understanding of the scale provided to them (Williams, Eston & Furlong, 1994). Previous research has suggested the measurement of perceived physical exertion in children hosts numerous limitations with the practice of category-ratio scales, designed for adults (Bar-Or, 1977; Eston & Williams, 1986; Mahon & Marsh, 1992; Mahon, Duncan, Howe & Del Coral, 1997; Mahon, Gay & Stolen, 1998; Robertson & Noble, 1997). One such limitation described, is that children under the age of 11 cannot associate numbers or words, consistently, to describe an exercise related feeling (Williams et al., 1994). Another limitation is that young children struggle to interpret verbal anchors outside of their normal vocabulary (Robertson et al., 2000). To tackle the limitations, Williams et al. (1994) developed a child friendly method of obtaining RPE, through the Children's Effort Rating Table (CERT). CERT has shown somewhat good levels of validity for use with children (Lamb, 1995), however individual variability has been shown in correlations between perceived and objective measures of intensity (Lamb & Eston, 1997). Due to the issues with CERT, a more appropriate choice of scale with children may indeed be the OMNI scale.

The OMNI scale is a category format scale encompassing both verbal and pictorial descriptors, positioned along a 0-10 incremental range (Utter, Robertson, Nieman & Kang, 2002). The term 'OMNI' is an acronym for the word omnibus, when used in the context of perceived exertion refers to a category scale with broadly generalisable measurement properties (Robertson et al., 2004). In the OMNI scale, the verbal descriptor is consistent by what is described in the associated picture (Robertson et al., 2000). Rodríguez-Marroyo and Antoñan (2015) reported that only a handful of studies (Haddad et al., 2011; Lugo, Capranica & Tessitore, 2014) have explored child specific RPE scales to monitor training load and exercise intensity in youth sports. Scales that contain pictorial and verbal descriptors appear to be more appropriate in collecting children's RPE (Roemmich et al., 2006). It has been suggested that children may focus on the pictorial descriptors rather than the verbal anchors, which they may not fully understand (Parfitt, Shepherd & Eston, 2007).

There are several alternatives to the OMNI scale in terms of pictorial descriptors; cycling (Robertson et al., 2000) (Figure 1), walking/running (Utter et al., 2002) (Figure 2), resistance training (Robertson et al., 2003) (Figure 3) and stepping (Robertson et al., 2005) (Figure 4). Since its creation as an alternative to RPE, a more suitable way for children to perceive their exertion, the OMNI scale has been altered for use with adults. The OMNI-Resistance Exercise Scale (OMNI-Res) was developed for use with young adults, in both upper- and lower-body exercises (Robertson et al., 2003). The pictorial descriptor, in this case, displayed an individual ‘weightlifting’.

Ratings of perceived exertion from the OMNI scale have been shown to be both valid and reliable for monitoring and self-regulating exercise, despite an evident limitation at the lower end response of the OMNI scale (0-3) (Mays, et al., 2010). It has been noted that it is not infrequent for individuals to respond with a rating of perceived exertion of “0” during low intensity exercise, as the corresponding verbal descriptor for “0” is “extremely easy” (Mays et al., 2010). This occurrence has appeared on different variations of the OMNI scale.

2.9.1 OMNI scale reliability

Pfeiffer, Pivarnik, Womack, Reeves and Malina (2002), reported higher levels of reliability in the OMNI scale compared to the Borg 6-20 scale, across two separate trials (0.95; 0.78, respectively) and single-day reliability (0.91; 0.64, respectively). High levels of reliability were detailed in Pfeiffer et al. (2002), when using adolescent females aged between 13-18 years. There was low standard error of the mean with the OMNI scale indicating low test-to-test variability in the scale. Pfeiffer et al. (2002)

explained that caution must be aired with their reliability findings since testing conditions differed between the first and second day to minimise participant burden.

2.9.2 OMNI scale validity

The OMNI cycling scale demonstrated higher levels of validity than the Borg 6-20 scale during treadmill exercise, regardless of the criterion measure, HR Max (OMNI – 0.86; Borg – 0.66), %VO2 Max (OMNI – 0.89; Borg - 0.70) (Pfeiffer et al., 2002). The OMNI cycling scale demonstrated greater validity in treadmill exercise in adolescent girls (13-18 years) than the walking/running scale in younger participants (6-13 years). The OMNI-RES scale has shown to be valid for both adult males and females in upper- and lower-body resistance exercise (Robertson et al., 2003). Robertson et al. (2003) used blood lactate as a co-criterion method, alongside total weight lifted. It was found that as blood lactate increased so did the RPE scores. Both concurrent and construct validity has been demonstrated in adults, both male and female in elliptical ergonometric exercise (Mays et al., 2010).

The OMNI walking/running scale has also displayed a linear increase in RPE scores alongside increasing exercise intensity (Utter et al., 2002). Utter et al. (2002) also demonstrated the scales validity by exhibiting a significant correlation between OMNI walking/running RPE and various physiological measures (%VO2 Max, HR), across different exercise intensities. Utilising a multi-stage cycle ergometer protocol, Robertson et al. (2000) demonstrated strong levels of validity in the OMNI cycling scale, against oxygen uptake and HR, in 8-12-year-old male and female, African American and Caucasian children. The construct validity for the OMNI scale has been demonstrated to monitor the physical demands of youth soccer players in training (Rodríguez-Marroyo & Antoñan, 2015).

2.10 Differential Ratings of Perceived Exertion

Whilst RPE offers a total measure of intensity, it may in fact offer an over-simplification of a vastly complex psychophysiological construct (Weston, Siegler, Bahnert, McBrian & Lovell, 2015). In essence, RPE may not capture the whole range of exercise-related perceptual feelings (Hutchinson & Tenenbaum, 2006). One's internal load relates to both the positive (e.g., fitness levels) (Gabbett, 2005; Gil-Rey, Lezaun & Los Arcos, 2015) and negative outcomes (e.g., fatigue, injury) (Gabbett, 2016) associated with training and/or match play.

As an example, a resistance training session and a cardiovascular, running-based endurance session may elicit a very similar RPE, despite the two sessions provoking highly dissimilar metabolic, cardiovascular, and neuromuscular responses. Differential ratings of perceived exertion (dRPE) may have the potential to overcome the lack of sensitivity thought to be associated with RPE (Weston, 2013; McLaren, Weston, Smith, Cramb & Portas, 2016). By employing dRPE it allows for the discrimination of acute sensory inputs by separating various facets of effort (Weston et al., 2015). Crucially, additional information can potentially be obtained using dRPE, compared with a single measure (McLaren, Smith, Spears & Weston, 2017). It is conceivable that dRPE may be able to distinguish between cardiovascular and neuromuscular/musculoskeletal load adaptations (Jaspers, Brink, Probst, Frencken & Helsen 2017; Vanrenterghem et al., 2017). McLaren et al. (2017) affirmed support for dRPE suggesting the various facets, in this case sRPE-B, sRPE-L, sRPE-U & sRPE-T were quantifying different internal measures.

It is thought that dRPE may be a more appropriate alternative for measuring internal load in soccer match-play (Weston et al., 2015; McLaren, Graham, Spears & Weston, 2016; Vanrenterghem, Nedergaard, Robinson & Drust, 2017; Barrett, McLaren, Spears, Ward & Weston, 2018). By obtaining a greater understanding of a player's internal load during match-play, more appropriate recovery strategies can be prescribed (Barrett et al., 2018). Differential ratings of perceived exertion may provide practitioners with a greater understanding of dose-response in training and match loads (Los Arcos, Martínez-Santos, Yanci, Mendiguchia & Méndez-Villanueva, 2015; Weston et al., 2015). McLaren et al. (2016) suggested that the application of dRPE in training load monitoring should be employed as an addition to sRPE and not as a direct replacement.

Despite the apparent advantages of dRPE, for the measurement of internal load, research into this area is still in its infancy and remains inconclusive (Gil-Rey, Lezaun & Los Arcos, 2015; Los Arcos et al., 2015). Greater understanding of the effectiveness of dRPE is required. McLaren, Taylor, MacPherson, Spears and Weston (2020) assessed the differences in RPE-B and RPE-L in both straight-line running (SLR) and change of direction running (CoD). Each group completed a set number of actions over different distances. The SLR group completed a 30m effort and the CoD group completed 2 x 10m efforts with a 180^{o} turn. The SLR group reported a greater RPE (RPE-B: 50 ± 16, RPE-L: 43 ± 16) than the CoD group (RPE-B: 42 ± 15, RPE-L: 35 ± 13). It was reported that RPE-B & -L increased considerably across multiple sprints. A greater RPE-B compared to RPE-L has also been witnessed in other forms of short high-intensity training, as McEwan, Arthur, Philips, Gibson and Easton (2018) found a greater mean RPE-B (80-85 AU) compared to RPE-L (71-75 AU) following 12 x 30s treadmill running intervals.

On the contrary, Maughan, MacFarlane and Swinton (2021) reported similar component loadings for sRPE (0.91), sRPE-B (0.89) and sRPE-L (0.88) under the same principal component, when conducting a principal component analysis. Maughan et al.

(2021) collected dRPE (CR-10) from adolescent male soccer players after training sessions across the course of a season. When data falls under the same principal component it highlights that the variables are correlated with one another within that specific principal component (Maughan et al., 2021). In soccer training, the variance explained between the facets of dRPE suggest that only a single training load measure may be necessary to monitor internal training load (Weaving, Marshall, Earle, Nevill & Abt, 2014; Maughan et al., 2021).

2.11 Small-sided games

Small-sided games (SSG) allow for the reproduction of soccer-specific physical outputs (e.g., short sprints & tackling) (Di Salvo et al., 2007; Dellal et al., 2012). There are several factors believed to influence, and exhibit, different physiological and psychological outputs from SSGs (Halouani, Chtourou, Dellal, Chaouachi & Chamari, 2017), including, but not limited to; pitch dimensions (Williams & Owen, 2007; Owen, Wong, McKenna & Dellal, 2011), number of players (Hill-Haas, Roswell, Coutts & Dawson, 2008; Brandes, Heitmann & Muller, 2012), game duration (Fanchini et al., 2011) and rules (Abrantes, Nunes, Maçãs, Leite & Sampaio, 2012; Dellal et al., 2012; Jake et al., 2012; Halouani, Chtourou, Dellal, Chaouachi & Chamari, 2014). Several studies have considered the effect of changing pitch dimensions on physiological output (Rampinini et al., 2007; Owen et al., 2011; Kelly & Drust, 2009).

2.11.1 Pitch Dimensions

Larger pitch areas have been associated with increased physiological load (RPE, HR) compared to smaller pitches, irrespective of player age or game-format (Little & Williams, 2007; Rampinini et al., 2007; Köklü, Albayrak, Keysan, Alemdaroğlu & Dellal, 2013; Hodgson, Akenhead & Thomas, 2014). It has been reported that as the pitch sizes increases, so do the player's physiological demands as players mean HR and mean peak HR increased linearly with pitch size (Owen, Twist & Ford, 2004) as well as physical demands (high speed running, total distance, max speed) and RPE (Casamichana & Castellano, 2010). However, in 4 vs. 4 SSGs across increasing pitch sizes; 20x25m; 25x30m; 30x35m, the highest mean peak HR was witnessed on the 'medium' pitch size (25x30m) with the lowest reported on the 'small' pitch size (20x25m) (Owen, Twist & Ford, 2004). It was also reported that 4 vs. 4 SSGs facilitated a lower mean HR than 11 vs. 11 on a full-size pitch, and the mean peak HR was considerably higher in 11 vs. 11 compared to 4 vs. 4 (Owen, Twist & Ford, 2004). However, the study involved professional soccer players (17.46 ± 1.05 years) (Owen, Twist & Ford, 2004) who were older and more experienced than those utilised in the current thesis. Kelly and Drust (2009) found no significant difference between mean HR and pitch dimensions, across three differing pitch sizes (30m x 20m; 40m x 30m; 50m x 40m). Fenner et al. (2016) used an 18.3m x 23m pitch for 4 vs. 4 SSGs for technical skills talent identification purposes. The rationale behind the pitch dimensions was that the pitch dimensions were used within normal training practices (Fenner et al., 2016). A pilot study, comparing the decided upon pitch dimensions with larger ones, reported no difference in technical outcomes and a similar physiological response (Fenner et al., 2016). The same pitch dimensions were utilised by Towlson et al. (2020b) in maturity matched/mis-matched bio-banded SSGs and it was reported that maturity matched bio-banding had limited effect on physical variables in pre-, circa- and post-PHV players. The small pitch dimensions may have limited any physical advantages, those advanced in maturation may possess, during mis-matched SSGs (i.e., pre-PHV vs post-PHV) (Towlson et al., 2020b).

When comparing differing pitch sizes (400m, 600m & 800m) across a range of surfaces (Ground, Artificial Grass & Natural Grass), it was reported that players reported a greater total distance on natural grass compared to artificial grass and ground, with the greatest distance difference seen on the 'Middle' pitch size (600m). The middle pitch size witnessed a greater player load than the 'Big' pitch size (800m) across all surface types. The greatest total output was witnessed on the natural grass surface followed by artificial grass with the lowest total output seen on ground (López-Fernández et al., 2019).

Kelly and Drust (2009) reported changes in technical actions across increasing pitch sizes and found that only tackles and shots were affected by pitch size. As the pitch size increased the number of technical actions decreased (Kelly & Drust, 2009). No significant difference was reported between the influence of pitch size on technical actions, including passing, dribbling, receiving, interceptions, or headers (Tessitore, Meeusen, Piacentini, Demarie & Capranica, 2006). Pitch-area restrictions (e.g., restricted-spacing; contiguous-spacing; free-spacing) in overloaded 9 vs. 10 large-sided games (LSGs) drastically decreased the physical and physiological output of elite soccer players (Gonçalves et al., 2017).

2.11.2 Number of Players

Increased player numbers (e.g., 4 vs.4 or 5 vs. 5) in SSGs enhance the predictability of positional organisation within teams (Aguiar, Gonçalves, Botelho, Lemmink & Sampaio, 2015) and the variability in cardiovascular demands (Aguiar, Botelho, Gonçalves & Sampaio, 2013), compared with lesser numbers (e.g., 2 vs 2 or 3 vs. 3). Owen, Wong, Paul and Dellal (2014) investigated three separate pitch size classifications, increasing in player numbers each time as pitch size increased. Each player format (e.g., 4 vs. 4, 5 vs. 5 – 11 vs. 11) included goalkeepers. The player ratio per player (m^2) increased from 1:94m^2 (4 vs. 4) up to 1:336m^2 (11 vs. 11). Owen et al., (2014) reported that as the number of players increased through the pitch sizes, the speed of play decreased, which was attributed to more space and therefore more time on the ball. It was also found that maximum velocity ($km.h^{-1}$), high intensity running distance (m) and sprint distance (m) were all significantly greater in large-sided games (9 vs. 9; 11 vs. 11) compared to the small- (4 vs. 4) and medium- (5 vs. 5 – 8 vs. 8) sided games. Brandes et al. (2012) explored the physiological response to player numbers in SSGs (2 vs. 2; 3 vs. 3; 4 vs. 4). They found the demands of 3 vs. 3 and 4 vs. 4 to be primarily aerobic, similarly to full size soccer match play, however 2 vs. 2 SSGs exhibited noticeable demands on the anaerobic energy system (Brandes et al., 2012). Utilising a sample of physically fit university students, Bondarev (2011) reported a significant difference in mean HR between 3 vs. 3 SSGs and 4 vs. 4, 5 vs. 5 and 6 vs. 6 SSGs. Jones and Drust (2007) presented the work-rate profiles observed in 4 vs. 4 SSGs and revealed a similar pattern to those observed in elite 11 a-side soccer match-play. There is a suggestion, therefore, for the use of 4 vs. 4 SSGs, as a surrogate for 11 a-side soccer match play, which may offer good ecological validity (Unnithan et al., 2012).

Hill-Haas, Coutts, Dawson and Roswell (2010) observed the physiological and psychological effects of under/overload teams and rules changes in SSGs. By 'underloading' a team the practitioner is purposely disadvantaging them of a player to exhibit different physiological responses (e.g., 3 vs. 4). 'Underloading' may be achieved by adding a 'floater' player who transitions to the team who have possession of the ball, creating a temporary overload/underload scenario (Hill-Haas et al., 2010). Teams who had been 'underloaded' (playing with less players) reported significantly greater RPE than those 'overloaded', despite no significant differences in high intensity running, %HRmax and blood lactate (La^-) (Hill-Haas et al., 2010).

2.11.3 Game Duration

The effect of SSG duration can alter the physical outcomes expected from each game, if the SSGs are longer in duration a greater cardiovascular output can be expected (Casamichana, Suarez-Arrones, Castellano & Román-Quintana, 2014). However, if SSGs are shorter in duration then you may expect an increased volume of higher-intensity actions (Casamichana et al., 2014). Fanchini et al. (2011) reported significantly lower HR responses in 6-min SSGs compared to 4-min SSGs with male amateur and professional soccer players (24 ± 4 years) and suggested this may be due to fatigue. Fanchini et al. (2011) reported that RPE increased through the bouts of SSGs, however was not significantly affected by an increase in game duration (Mean RPE; 2-min, Bout 1-3; 6.3, 6.7, 7.2; 4-min, Bout 1-3; 6.2, 6.9, 7.3; 6-min, Bout 1-3; 6.1, 6.8, 7.5). The duration of the SSGs did not influence the technical actions nor the players technical skills (Fanchini et al., 2011). Fenner et al. (2016) demonstrated consistent physiological output between 5-minute game durations and shorter durations. As the exercise bouts increased across 2 vs. 2, 3 vs. 3 and 4 vs. 4 match-play the number of high intensity actions and the technical performance of the players decreased (Dellal, Drust & Lago-Penas, 2012).

2.12 The Research Problem

Bio-banding refers to the grouping of individuals based upon their biological age as opposed to their chronological age (*see 2.1.2 Bio-Banding*). By separating players based upon their biological age it is believed to minimise the effect of physical advantage and promote competitive fairness (Cumming et al., 2017a). The use of bio-banding has been well received in a bio-banded tournament, from both early- and late-maturing players (Cumming et al., 2018). However, despite the implementation of bio-banding in youth soccer academies (Abbott et al., 2019), there is still limited evidence for the use of bio-banding as a means of discovering talented soccer players (Towlson et al., 2020b). Conversely, it must be appreciated that bio-banding should not be used as a replacement to chronological age competition, it must merely complement it (Abbott et al., 2019). Most bio-banding research has been conducted in traditional youth soccer formats (7 vs. 7, 9 vs. 9 or 11 vs. 11), on competition size soccer pitches for the appropriate age group and team size (Cumming et al., 2017b; Thomas et al., 2017; Abbott et al., 2019; Bradley et al., 2019; Romann et al., 2020). However, Towlson et al. (2020b) utilised a SSGs approach to bio-banding and suggested that the use of SSGs in bio-banding research allows for the development of psychological skills, crucial in the progress of late maturing players. Small sided games play a central role in talent identification models (Fenner et al., 2016). Small sided games have the ability to replicate the physical and technical demands of competitive soccer match play (Kelly & Drust, 2009; Dellal et al., 2011b). It must be noted however when discussing the use of SSGs, Towlson et al. (2020b) reported the pitch dimensions used in the research (52.6 m^2 per player), may have been too small to elicit any meaningful physical differences between early- and late-maturing players. Towlson et al. (2020b) suggested more research is needed to explore the effect, and match-to-match variability, of pitch size in bio-banded SSGs. Towlson et al. (2020b) reported meaningful sRPE-TL differences in mis-matched SSGs, despite no noteworthy differences in internal load (mean HR). The difference in sRPE may have been as a result of pre-PHV players perceiving a different facet of effort (e.g., technical, tactical, psychological) as physcial effort in SSGs (Towlson et al., 2020b). Differential ratings of perceived exertion allows for the discrimination of acute sensory inputs by splitting different components of effort perception (Weston et al., 2015) (*see 2.10 Differential Ratings of Perceived Exertion)*. McLaren et al. (2017) found that the different facets of dRPE (sRPE-B, sRPE-L, sRPE-U & sRPE-T) were all quantifying different internal measures. The use of dRPE has been further extenuated by Weston et al. (2014), McLaren et al. (2016; 2018) and Barrett et al. (2018) in support of the use of dRPE across match-play and various training types. Nevertheless, dRPE research is still in its infancy and remains inconclusive (Gil-Rey, Lezaun & Los Arcos, 2015; Los Arcos et al., 2015), this is particularly evident in youth soccer where limited research exists in the use of dRPE to measure internal load (Wright et al., 2020; Maughan et al., 2021). The limited research into dRPE in youth soccer has shown that dRPE may not actually measure what it is intending to measure, as similar component loadings for sRPE (0.91), sRPE-B (0.89) and sRPE-L (0.88) were reported under the same principal component (Maughan et al., 2021). The variance explained between the facets of dRPE suggest that only a single training load measure would be needed (Weaving et al., 2014; Maughan et al., 2021). Wright et al. (2020) reported significant differences between sRPE-B and sRPE-L in distinct training sessions (e.g., resistance and fitness), however found a majority trivial differences in match-play and training sessions. Therefore, there is a greater need to understand the effects of different pitch sizes on the perceived efforts of youth soccer players in bio-banded competition. The research also looks to expand on the limited knowledge of differential ratings of perceived exertion in a youth population.

2.13 Aims & Hypothesis

The first aim of the research was to enhance our understanding of differential ratings of perceived exertion in the youth population through a bio-banded format. The second aim was to appreciate the effect of pitch size on differential ratings of perceived exertion within the same bio-banded academy population. The research can help to comprehend the usefulness of differential ratings of perceived exertion within youth academy soccer, as well as helping gain a greater understanding of a player's internal response to maturity matched/ mis-matched bio-banding on increasing pitch sizes through SSGs. We hypothesised that post-PHV players will produce lower ratings in dRPE-Overall, dRPE-B and dRPE-L, when compared with pre-PHV players, across all pitch conditions. We also hypothesised that dRPE-Overall and dRPE-B will increase linearly with pitch size, in both pre- and post-PHV players. We also hypothesised there will be no significant difference between pre- and post-PHV players in dRPE-T, regardless of pitch size condition, rather any differences would be based upon chronological age.

3.0 Methods

3.1 Participants

Forty-three highly trained academy soccer players (U12 = 10, U13 = 15, U14 = 18) from two English professional soccer academies (EPPP Category 1: n = 1; EPPP Category 2: n = 1), participated in the study. All players played in the Youth Development Phase (YDP). Utilising the Khamis-Roche method (Khamis-Roche, 1994), the players were split into two separate maturity specific groupings, pre-PHV (<89.9 %EASA) and post-PHV (>90.0 %EASA). The method employed %EASA as a determinant of maturity status (Khamis & Roche, 1994). The anthropometric and maturational differences between pre- and post-PHV teams are detailed in Tables 1 and 2. Goalkeepers were exempt from participating in the study due to the differences in physical characteristics of playing position between goalkeepers and outfield players, as goalkeepers cover ~4km per game (Carling, Bloomfield, Nelson & Reilly, 2008), whereas outfield players cover ~10-12km per game, depending upon playing position, (Dellal et al., 2011a) in 11 a-side match play. As the players were under the age of 18 years, parental informed consent was collected from their parent/guardian. The parents and players were made aware of their right to withdraw. The investigation was approved by the University of Hull ethics committee, Ethics Number: FHS 187.

Table 1. Anthropometric and maturity characteristics of both pre- and post-PHV teams for the maturity matched/mis-matched bio-banded SSGs.

Bio-Banded SSGs
Anthropometric and Maturity Characteristics

Pitch Size	Team	Mean Decimal Age	Mean %EASA	Mean Stature (cm)	Mean Body Mass (kg)
Small (17m x 17m) (36m²)	Post-PHV 1	13.65 ± 0.38	93.6 ± 1.5	170.1 ± 6.6	54.20 ± 6.01
	Post-PHV 2	13.69 ± 0.49	92.2 ± 2.0	165.0 ± 6.6	49.10 ± 3.85
	Pre-PHV 1	12.30 ± 0.85	84.3 ± 3.0	149.6 ± 7.5	39.23 ± 6.53
	Pre-PHV 2	12.26 ± 0.50	84.6 ± 1.3	154.1 ± 6.8	40.70 ± 4.80
Medium (24m x 24m) (72m²)	Post-PHV 1	13.59 ± 0.48	93.3 ± 1.7	167.7 ± 7.6	53.18 ± 5.76
	Post-PHV 2	13.60 ± 0.44	91.6 ± 2.0	164.9 ± 6.1	48.69 ± 3.40
	Pre-PHV 1	12.34 ± 0.77	85.4 ± 2.6	147.2 ± 14.6	39.95 ± 5.84
	Pre-PHV 2	12.62 ± 0.34	85.8 ± 2.4	156.9 ± 8.6	44.40 ± 6.29
Large (29.5m x 29.5m) (109m²)	Post-PHV 1	13.61 ± 0.38	93.2 ± 2.0	168.5 ± 6.1	53.90 ± 5.65
	Post-PHV 2	13.63 ± 0.47	91.7 ± 2.2	164.3 ± 6.3	48.70 ± 3.68
	Pre-PHV 1	12.31 ± 0.85	84.8 ± 3.1	150.5 ± 6.3	39.95 ± 5.80
	Pre-PHV 2	12.22 ± 0.58	84.7 ± 1.7	153.8 ± 7.4	42.50 ± 5.20
Expansive (34m x 34m) (144.5m²)	Post-PHV 1	13.74 ± 0.31	93.5 ± 1.6	170.4 ± 6.8	54.58 ± 5.94
	Post-PHV 2	13.43 ± 0.48	91.4 ± 2.1	165.9 ± 7.8	51.03 ± 6.57
	Pre-PHV 1	12.24 ± 0.91	83.9 ± 3.3	147.3 ± 6.1	38.60 ± 6.57
	Pre-PHV 2	12.26 ± 0.50	84.6 ± 1.3	154.1 ± 6.8	40.70 ± 4.80

Mean (±SD) decimal age, %EASA, stature (cm) and body mass (kg) for the bio-banded SSGs across all four pitch sizes.

Table 2. Anthropometric and maturity characteristics of all four mixed maturity teams for the mixed maturity SSGs.

Mixed Maturity SSGs Anthropometric and Maturity Characteristics					
Pitch Size	**Team**	**Mean Decimal Age**	**Mean %EASA**	**Mean Stature (cm)**	**Mean Body Mass (kg)**
Small (17m x 17m) (36m^2)	Mixed 1	13.13 ± 0.74	87.4 ± 4.5	157.8 ± 12.6	45.40 ± 10.59
	Mixed 2	12.97 ± 0.98	88.5 ± 5.6	157.1 ± 10.9	43.18 ± 8.65
	Mixed 3	12.38 ± 1.07	87.5 ± 4.2	160.4 ± 9.0	44.50 ± 5.71
	Mixed 4	12.96 ± 1.01	89.6 ± 4.9	161.9 ± 11.4	48.40 ± 7.49
Medium (24m x 24m) (72m^2)	Mixed 1	12.91 ± 0.76	87.2 ± 4.2	151.0 ± 18.2	44.20 ± 9.67
	Mixed 2	13.11 ± 0.80	89.3 ± 4.8	158.4 ± 8.9	45.76 ± 6.93
	Mixed 3	12.94 ± 0.80	89.5 ± 3.2	164.3 ± 5.9	47.11 ± 3.36
	Mixed 4	13.14 ± 0.85	90.2 ± 4.3	162.9 ± 10.0	48.90 ± 7.82
Large (29.5m x 29.5m) (109m^2)	Mixed 1	13.14 ± 0.74	87.1 ± 4.2	157.0 ± 11.3	45 ± 9.75
	Mixed 2	13.03 ± 0.96	88.6 ± 5.6	158.5 ± 9.8	45.80 ± 7.41
	Mixed 3	12.47 ± 0.92	88.2 ± 3.4	158.7 ± 5.2	44.27 ± 4.31
	Mixed 4	12.86 ± 1.09	89.9 ± 4.6	161.8 ± 11.5	48.61 ± 7.08
Expansive (34m x 34m) (144.5m^2)	Mixed 1	13.81 ± 0.76	87.6 ± 4.8	156.8 ± 11.7	45.10 ± 10.41
	Mixed 2	12.91 ± 0.95	88.2 ± 5.6	158.4 ± 10.5	44.15 ± 7.96
	Mixed 3	12.70 ± 1.04	88.3 ± 4.4	161.3 ± 13.6	47.20 ± 10.20
	Mixed 4	12.84 ± 1.02	89.2 ± 5.1	160.5 ± 11.6	48.20 ± 8.06

Mean (±SD) decimal age, %EASA, stature (cm) and body mass (kg) for the mixed maturity SSGs across all four pitch sizes.

3.2 Design

3.2.1 Game Format

Four teams competed on each pitch size in the bio-banded game format, post-PHV 1, post-PHV 2, pre-PHV 1 and pre-PHV 2. Players competed in six SSGs, three maturity matched/mis-matched bio-banded, for example post-PHV 1 vs post-PHV 2 was a maturity matched bio-banded SSG, whereas post-PHV 1/2 vs pre-PHV 1/2 was a maturity mis-matched SSG. The maturity matched/mis-matched SSGs were proceeded by three mixed maturity games where the players were separated into four mixed maturity teams, mixed maturity 1,2,3 and 4. The SSGs were played across increasing pitch sizes (Small: 17m x 17m (36.1m^2 per player), medium: 24m x 24m (72m^2 per player), large: 29.5m x 29.5m (109m^2 per player) and expansive: 34m x 34m (144.5m^2 per player)). The pitch sizes used were selected to challenge the players in different ways both technically and physically. The pitch sizes were selected to create an environment that is both restricting, compared to the relative pitch size in age group competition (U12 (9 vs 9) - 80 x 50 (222m^2) and U13/U14 (11 vs 11) - 90 x 55 (225m^2) (The Football Association, 2012)) and expansive compared to the relative pitch sizes utilised in previous SSG studies (Fenner et al., 2016; Towlson et al., 2020b (52m^2)). All games were played on artificial grass (4G) surfaces due to several uncontrollable variables, such as facilities available and the time of research, for example the research was conducted at night, so the pitch was required to be lit by floodlights.

Each SSG was 5 minutes in duration with a standardised set of rules taken from previously published research (Fenner et al., 2016; Towlson et al., 2020b). All players were made aware of the rules prior to the commencement of their first SSG. The rules stated that players could only score in the attacking half of the pitch, all restarts of play were kick ins (e.g., throw ins had to be kicked in), there were also no corners, instead possession was given to the team that won the corner on their goal line. There were also additional balls placed around the perimeter of the playing area to encourage fast restarts and no stoppages for injuries (Owen et al., 2014). The rules were enforced by the same referee across each game and testing week. Fenner et al. (2016) demonstrated consistent physiological output between 5-minute game durations and shorter durations. The 5-minute game protocol is consistent with that of previous SSG research (Unnithan et al., 2012; Fenner et al., 2016; Towlson et al., 2020b). Between SSGs a standardised 3-minute off pitch passive recovery was performed (Fenner et al., 2016). By adopting a standardised passive recovery protocol, it allowed the research team to control the time spent away from games to ensure the players were not overexerting themselves which may have affected their performance in the SSGs. The same procedure was repeated the following week with the same groups of players and method.

The data collection utilised a mini league game format with each team playing each other once. Four teams competed against one another and were separated by biological maturity (2 pre-PHV; 2 post-PHV). Upon completion, a 30-minute grace period followed, this was selected as it allowed for sufficient recovery of those who played in the last game and was a time which was deemed to be practical in the context of the time restraints that were placed upon each data collection session. After the grace period four mixed maturity teams, consisting of four players, were systematically created to include 2 pre-PHV and 2 post-PHV players per team. The lead researcher assigned a number to each player (1-4). For example, each player that was given the number one from the 4 bio-banded teams (Post-PHV 1, Post-PHV 2, Pre-PHV 1 & Pre-PHV 2) comprised mixed maturity team one, this method was used for the creation of all mixed maturity teams. This method allowed for a consistent and fair approach to the selection of the mixed maturity teams.

3.2.2 Anthropometrical and maturity measures

The Khamis-Roche method (Khamis & Roche, 1994) was considered the most appropriate method to estimate maturity status, due to its previous use to 'bio-band' adolescent soccer players (Cumming et al., 2017). Towlson et al. (2020b) explained the Khamis-Roche method (Khamis & Roche, 1994) outperformed the Fransen method (Fransen et al. 2017) in eight of ten physical variables. The Khamis-Roche, %EASA, method (Khamis & Roche, 1994) possesses greater prediction qualities, than the original aPHV equation (Mirwald et al., 2002) (Towlson et al., 2020a). The Khamis-Roche, %EASA, method (Khamis & Roche, 1994) successfully identified 96% of players experiencing the adult height window, whilst the Mirwald aPHV equation (Mirwald et al., 2002) only identified 65% experiencing PHV (Parr et al., 2020).

The Khamis-Roche method (Khamis & Roche, 1994) employs interactions between stature, decimal age, body mass and mid-parental height (Towlson et al., 2020a). The interactions allow for each player to be categorised as a percentage of their EASA. The Khamis-Roche (Khamis & Roche, 1994) method is also non-invasive, therefore there are less ethical concerns when compared with highly invasive methods of obtaining maturity status, such as sexual maturity, which would inevitably raise several ethical questions. Mid-parental height was obtained through self-reported parental height, which is consistent with previous research within the field (Cumming et al., 2017b; Towlson et al., 2020b). The self-reported heights were adjusted for over-estimations based on a sample of North American adults (Epstein et al., 1995).

As well as mid-parental height, the Khamis-Roche method also requires the decimal age of the individual, their stature and body mass. Each player's standing stature was collected using a free-standing stadiometer (Seca 213, Stadiometer, Germany), following the appropriate method prescribed by the International Society for the Advancement of Kinanthropometry (ISAK) (Norton, 2018). The method involved the player standing on the footprints, on the stadiometer, with their feet together and their heels, buttocks and upper part of the back touching the back board and looking forward and not wearing shoes. A practitioner then gently placed their hands on the players face, across their cheekbone with their fingers around the base of the head carefully positioning the head in the Frankfort plane. The Frankfort plane requires the Orbital (the lower edge of the eye) in the same horizontal plane as the Tragion (centre of the ear hole), when aligned the vertex is the highest point on the cranium. The practitioner then instructed the player to take a deep breath. As the player inhaled the practitioner maintained the head in the Frankfort plane. At this point, a second practitioner pushed down the measuring marker onto the players head with enough force to stop on the cranium but as not to hurt the individual. This marker gives an accurate reading of the player's stature in centimetres. Players body-mass were obtained by stepping onto the measuring scales (Seca 875 electronic class III, Germany) whilst wearing normal training attire and similarly, shoes were not worn. The procedure for both stature and body mass was repeated to gain a second reading. Each reading was accurate to 0.1 cm or 0.1 kg. The mean of the values was calculated as the standing stature and body-mass, however if the two values varied by ≥ 0.4 cm or 0.4 kg a third measure was taken with the median of the three values being calculated as the stature (Towlson, Cobley, Parkin & Lovell, 2018).

3.3 Physiological Measures

3.3.1 Internal Load

Players internal load were recorded through the collection of RPE and dRPE after each SSG. Following each SSG, players rated their perceived exertion for that particular game. Players stood behind a cone located 5m from the researcher designated to collect the dRPE. By separating each player by 5m, when completing their individual dRPE score, it aimed to reduce player influence when giving dRPE ratings. The research aimed to decrease the chances of auditory and visual distraction from the environment. Distractors are thought remove focus from a person's internal sensors (Chow & Etnier, 2017). When using music and video (auditory and visual) distractors, participants reported a lower RPE, compared to no distractions (Chow & Etnier, 2017), thus suggesting distractors disassociate us from our internal feelings. The researcher presented a 7" Android tablet (Iconia One 7 BI-750, Acer Inc., Taipei, Taiwan), with a custom built, pre-loaded, application for the collection of dRPE. It has been suggested that the presence of others at the time of RPE collection, in tandem with personality factors (depression, anxiety, introversion and extraversion), can influence RPE ratings (Morgan, 1973, 1994). The researcher collecting dRPE did their best to avoid influencing or observing the players selections. Despite several precautions taking place other influences can appear within the environment, including weather conditions, instructions regarding exercise and general distractors (Haddad, Stylianides, Djaoui, Dellal & Chamari, 2017).

The players completed their dRPE on a specially designed tablet application with the assistance of an OMNI walking/running pictorial scale (Utter, Robertson, Nieman & Kang, 2002). Players reported dRPE for the 'Overall perception of exertion', 'Breathlessness', 'Leg muscle exertion' and 'Technical/mental/cognitive demands'. The researcher also modified the OMNI walking/running pictorial scale to benefit the players who may not understand what is being asked of them (See figure 5, appendices). The tablet application had been utilised in previous research with a sample of elite soccer players (Barrett et al., 2018). It was felt that the scale needed to be altered slightly to become more 'child friendly', as it has been suggested, on numerous occasions, category-ratio scales designed for adults hold a number of limitations when used within a youth population (Bar-Or, 1977; Eston & Williams, 1986; Mahon & Marsh, 1992; Mahon, Duncan, Howe & Del Coral, 1997; Mahon, Gay & Stolen, 1998; Robertson & Noble, 1997). It has been suggested that scales using both verbal and pictorial descriptors may be more suitable for the collection of RPE in children (Roemmich et al., 2006). It is thought that children may not be able to fully comprehend the verbal descriptors, so pictorial cues aim to enhance their understanding (Parfitt, Shephard & Eston, 2007). The walking/running OMNI scale (Utter et al., 2002) was thought to be the most appropriate pictorial scale, due to the pictorial cues representing a similar movement pattern to that of soccer. The scale was modified so that the verbal cues on the tablet application were mirrored on the OMNI scale.

Upon completing their dRPE, players would then approach another research who followed the same protocol as detailed above. The researcher collected an overall RPE using the Borg CR-10 scale (Borg, 1980). The CR-10 RPE was collected manually by the research who assigned the number given by the player to the corresponding fixture on a clipboard. By collecting both CR-10 and CR-100 RPE it allowed for comparisons between the two scales, which have previously been described as interchangeable (Borg, 2007; Fanchini et al., 2016).

Players wore a HR belt (T31, Polar Electro Oy, Finland) which was worn across the sternum of the individual and adjusted to fit so that it would not move but was also comfortable. The HR belt allows for the accurate collection of players HR (beats.min^{-1}) throughout the session. Mean HR was utilised to obtain each player's internal training load. Mean HR reflects upon a summation of each point at which heart rate data is collected (Bannister, 1991). Some have argued that mean HR does not accurately reflect the demands of long-duration, intermittent team sports (Stagno, Thatcher & Van Someren, 2007). However, due to the short duration of the SSGs, utilised in the current thesis, mean HR was decided upon rather than maximal HR. Heart rate is often utilised as a criterion method in research due to its ease to obtain, however it has been suggested that HR may not be the most applicable method for children due to the high variability witnessed with children (Pfeiffer et al., 2002). The HR belt was synced to a micro-electro-mechanical sensor device, recorded at every 5s interval.

3.3.2 External loads

Each players' external load was quantified through the use of a Micro-Electro-Mechanical Sensor (MEMs) device, containing a 10Hz Global Positioning System (GPS) and a 100 Hz triaxial accelerometer (Optmieye S5, Catapult Innovations, Melbourne, Australia). The device was located between the player's scapulae in a specially designed vest (Weston et al., 2015). It has been suggested the 10Hz model offers significantly greater validity and inter-unit reliability when compared with a 5 Hz model (Varley, Fairweather & Aughey, 2011) and measured movement demands with more validity and reliability than the 15 Hz model (Johnston, Watsford, Kelly, Pine & Spurrs, 2014). Rampinini et al. (2015) argued that both the 5 Hz and 10 Hz devices were equally accurate in calculating total distance and mean power, however only the 10 Hz device demonstrated a comfortable level of accuracy to appraise distance at high speeds and time spent at high power.

The MEMs device allows for a number of physical parameters to be documented, such as; Low intensity running (<3.6 m/s^{-1}); High intensity running (3.6 - 4.4 m/s^{-1}); Very high intensity running (4.4-5.3 m/s^{-1}); Sprinting (5.3 m/s^{-1}) and total distance covered (m), as well as PlayerLoad™ (AU). The intensity thresholds in this research were taken from Buchheit, Mendez-Villanueva, Simpson and Bourdon (2010) who employed the same thresholds with U13-U18 youth soccer players. Buchheit et al. (2010) used kilometres per hour, so these figures were altered to meters per second to remain consistent throughout the research, this is calculated by multiplying the kilometre per hour by 5 and then dividing that number by 18. The same intensity thresholds have also been utilised in more contemporary research (Towlson et al., 2020b). The match-play demands of elite senior soccer players have been described previously, with studies reporting distance covered across a number of defined speed thresholds (running, 4.0–5.5 m/s^{-1}; high-speed running, 5.5–7.0m/s^{-1}; sprinting, >7m/s^{-1}; Bradley et al., 2009). However, it would be inappropriate to catalogue youth soccer players under the same thresholds due to the inherent differences in performance capabilities (Harley et al., 2010).

Players were also equipped with an inertial measurement device (IMU) (Playermaker™, Tel Aviv, Israel) which was placed in a specially designed silicone casing placed across the player's football boot, with the device fitting on the lateral malleolus of the ankle (Gad et al., 2020). The main use of the Playermaker™ unit was to collect technical data for the players from each SSG. Traditional IMUs, placed between the scapular, are unable to monitor the kicking actions of players (Barrett, Midgley & Lovell, 2014; Vanrenterghem, Nedergaard, Robinson & Drust 2017; Nedergaard et al., 2018), however when the IMU is placed on the feet these kicking actions can be monitored and quantified (Gad et al., 2020). The advantage of collecting such data was that the research could obtain a greater understanding of how players technical performance was affected by the bio-banded format. In turn, how technical performance influenced players perceived exertion. In the research the main interest from the Playermaker^{TM} unit was to collect the number of '*releases*' for each player. A *release* included any action in which the player kicked the ball. A *release* was classified as, but not limited to; a pass, shot, cross or tackle which resulted in the ball being controlled by another player. Previously, the Playermaker^{TM} foot-mounted IMU has shown good levels of concurrent validity and intra-unit reliability for the quantification of releases in elite soccer players (Marris, Barrett, Abt & Towlson, 2021).

3.4 Statistical analysis

The estimates were all detailed at 95% confidence intervals with analysis undertaken on raw data. Due to technological errors, there were several missing data points which were noted and excluded from data analysis. Equally, known erroneous data, such as incorrect dRPE scores, as explained by the players during the data collection process, were also deleted and removed from the final dataset. In the SPSS dataset all erroneous or missing data were defined as a '0' which allowed the programme to recognise the data was missing, as detailed by Field (2014). The rationale behind choosing '0' was that it was not found within the data that had been collected so offered a simple number to represent missing or erroneous data. The data analysis was separated into two parts; the first being maturity matched/mis-matched bio-banded SSGs (Post-PHV 1 vs Post-PHV 2, Post-PHV 1/2 vs Pre-PHV 1/2 and Pre-PHV 1 vs Pre-PHV 2), in the analysis of these SSGs, both post-PHV teams were merged together in post-PHV vs pre-PHV SSGs, and likewise for pre-PHV. The second measure of the statistical analysis was the mixed maturity SSGs. In order to maintain consistency in the statistical analysis, the four teams were analysed in tangent with the maturity matched bio-banded SSGs. The mixed maturity SSGs were labelled as Mixed 1, Mixed 2 and Mixed 3. Mixed 1 emulated the post-PHV vs pre-PHV SSG as Mixed 1 & 2 were merged together as one team with Mixed 3 & 4 the other team. Mixed 2 analysed Mixed 1 vs Mixed 2 and Mixed 3 analysed Mixed 3 vs Mixed 4.

3.4.1 Linear Mixed Model

The research adopted a linear mixed model (SPSS v26, IBM Corp, Armonk, NY, USA) to determine the effects of dRPE across numerous parameters, such as pitch size and maturity status. In the linear mixed model analysis, the key performance indicators analysed (TD, Mean HR, RPE CR-10, dRPE CR-100 Overall, dRPE-B, dRPE-L, dRPE-T, Releases) were compared per fixture (Post-PHV 1 vs Post-PHV 2, Post-PHV 1/2 vs Pre-PHV 1/2, Pre-PHV 1 vs Pre-PHV 2, Mixed 1, Mixed 2 and Mixed 3) on all pitch sizes. Within the linear mixed model analysis, the fixed effect was always maturity status so that pre- and post-PHV players would be compared against one another. Descriptive statistics were also selected in the analysis. Finally, in the estimated marginal means, maturity status was selected as the research was concerned with the mean score for both pre- and post-PHV players. A SIDAK confidence interval adjustment was selected for when comparing the main effects.

3.4.2 Principal Component Analysis

The research employed principal component analysis (PCA) (JASP Version 0. 14. 1) to better understand the relationship of variables. PCA correlates the chosen variables against one another, if a set of variables are seen to measure the same parameter it is showing that one may be suffice rather than all of them in data collection. Within the current thesis any principal component with an eigenvalue of greater than one was retained. The number of principal components, per analysis, were determined by the eigenvalues. A PCA was completed for each fixture type (Post-PHV 1 vs Post-PHV 2, Post-PHV 1/2 vs Pre-PHV 1/2, Pre-PHV 1 vs Pre-PHV 2, Mixed 1, Mixed 2 and Mixed 3). An orthogonal varimax rotation was also utilised within the PCA. Component Loadings for each principal component were retained if the value was greater than 0.4. Within the results section (*4.9 Principal component analysis*) the component loadings for each key performance indicator and their principal component are displayed as they appear within the principal component tables (*see Tables 7-30*).

4.0 Results

Each table (3, 4, 5 and 6) specifically details each key performance indicator with the mean (± SD), effect size (ES) and confidence intervals (*p*) across all pitch sizes. The results tables are displayed in the appendices section of the thesis. The tables are presented in a manner that makes it simple for the reader to understand what it being presented. All significant values are presented with an Asterix (*) so the reader can easily see where the significance values fall.

4.1 Total distance covered

There was no significant difference between pre- and post-PHV players for total distance covered on the small (ES = 0.47 – *small*), medium (ES = 0.52 – *small*) or expansive pitch (ES = 0.34 – *small*) sizes. However, there was a significant difference in total distance covered on the large pitch size, in the post-PHV vs pre-PHV SSG as the post-PHV (553 ± 56m) players covered a significantly greater distance than the pre-PHV (515 ± 43m) players (difference 38m, ES = 0.78, *p = 0.006 - moderate*). Regardless of SSG type (Post-PHV 1 vs Post-PHV 2; Post-PHV vs Pre-PHV; Pre-PHV 1 vs Pre-PHV 2), post-PHV players covered a greater mean total distance than pre-PHV players on the small, medium and large pitch sizes. However, on the expansive pitch size, pre-PHV players covered a greater total mean distance.

In the mixed maturity SSGs a significant difference in total distance covered on the small (Mixed 3; Post-PHV – 427 ± 17m, Pre-PHV – 360 ± 55m, difference 67m) and large (Mixed 1; Post-PHV – 530 ± 47m, Pre-PHV – 488 ± 45m, difference 42m) pitch sizes, were reported, as post-PHV players covered a greater total mean distance than pre-PHV players (ES = 1.86, 0.92, *p = 0.027; p = 0.002 – large; moderate,* respectively). Regardless of SSG type (Mixed 1; Mixed 2; Mixed 3), post-PHV players covered a greater mean distance than pre-PHV players across all pitch sizes.

When comparing the pre- and post-PHV players in maturity matched bio-banded (Post-PHV 1 vs Post-PHV 2; Pre-PHV 1 vs Pre-PHV 2) SSGs against maturity mis-matched SSGs (Post-PHV vs Pre-PHV), post-PHV players covered a greater mean distance in maturity matched bio-banded SSGs across all pitch sizes (small – 444 ± 58m; medium – 517 ± 43m; large – 574 ± 55m; expansive – 555 ± 50m) compared to the mean total distance covered in the maturity mis-matched SSGs (small – 436 ± 42m; medium - 493 ± 92m; large – 553 ± 56m; expansive – 512 ± 134m). In contrast, pre-PHV players covered a greater mean total distance in maturity mis-matched SSGs on the small (415 ± 48m), medium (458 ± 42m) and large (515 ± 43m) pitch sizes compared to the maturity matched bio-banded SSGs (small - 399 ± 39m; medium - 484 ± 44m; large – 523 ± 51m). However, on the expansive pitch condition pre-PHV players covered a greater mean total distance in maturity matched bio-banded SSGs (549 ± 51m) compared to the maturity mis-matched SSGs (542 ± 42m).

4.2 Heart Rate

In the maturity mis-matched SSGs there was a significant difference in the Post-PHV vs Pre-PHV SSGs on the large pitch size as post-PHV (165 ± 22 beats.min^{-1}) players recorded a significantly greater mean HR than pre-PHV (152 ± 26 beats.min^{-1}) players (difference 13 beats.min^{-1}, ES = 0.57, $p = 0.045$, *small*). There were no other significant differences between pre- and post-PHV players in the maturity mis-matched SSGs on the other pitch sizes. Despite there being no significant difference across any other pitch conditions the effect sizes ranged from *trivial* to *large.* A *large* effect size was witnessed in Post-PHV 1 vs Post-PHV 2 SSG on the small pitch size (ES = 1.26, *p* =

0.081). A *moderate* effect size was witnessed on numerous occasions across varying pitch sizes in Post-PHV 1 vs Post-PHV 2 (ES = 0.66, *p = 0.314*) and Pre-PHV 1 vs Pre-PHV 2 (ES = 0.89, *p = 0.229*) on the medium pitch size, Post-PHV 1 vs Post-PHV 2 (ES = 0.65, *p = 0.247*) on the large pitch size and Post-PHV 1 vs Post-PHV 2 (ES = 1.09, *p = 0.130*) and Pre-PHV 1 vs Pre-PHV 2 (ES = 0.79, *p = 0.359*) on the expansive pitch size. Irrespective of SSG type (Post-PHV 1 vs Post-PHV 2; Post-PHV vs Pre-PHV; Pre-PHV 1 vs Pre-PHV 2) post-PHV players recorded a greater mean HR for the SSGs on the small, large and expansive pitch sizes (difference, 5 beats.min^{-1}, 7 beats.min^{-1} and 9 beats.min^{-1}, respectively). The pre-PHV players displayed a greater mean HR on the medium pitch size (difference 6 beats.min^{-1}).

There was no significant difference between pre- and post-PHV players in the mixed maturity SSGs across all pitch sizes. Effect sizes, however, ranged from *trivial* to *moderate.* A *trivial* effect size was found on the medium pitch size (Mixed 1, ES = 0.19, *p= 0.533* and M2, ES = 0.13, *p = 0.812*), the large pitch size (Mixed 1, ES = 0.09, *p = 0.763*) and the expansive pitch size (Mixed 1, ES = 0.19, *p = 0.514*). A *moderate* effect size was found on the small (Mixed 2, ES = 1.01, *p = 0.082*; Mixed 3, ES = 0.66, *p = 0.287*), the medium (Mixed 3, ES = 1.12, *p = 0.129*) and the large (Mixed 2, ES = 0.65, *p = 0.343* and Mixed 3, ES = 0.97, *p = 0.238*) pitch sizes. Across the mixed maturity SSGs, post-PHV players recorded a greater mean HR on the small and large pitch sizes, whilst the pre-PHV players displayed a greater mean HR on the medium and expansive pitch sizes.

4.3 Ratings of Perceived Exertion using Category Ratio - 10

The maturity matched bio-banded SSGs yielded a significant difference in the Post-PHV 1 vs Post-PHV 2 SSG, on the large pitch size, as Post-PHV 1 (4.57 ± 0.79 AU) players reported a significantly lower RPE score than Post-PHV 2 (5.50 ± 0.76 AU) players (mean difference 0.93 AU, ES = 0.12, $p = 0.037$, *trivial*). In the maturity mis-matched bio-banded SSGs, Post-PHV vs Pre-PHV, pre-PHV (4.96 ± 1.00 AU) players reported a significantly greater RPE than post-PHV (4.07 ± 0.98 AU) players (mean difference 0.89 AU, ES = 0.90, $p = 0.001$, *moderate*) also on the large pitch size. A significant difference was found on the expansive pitch size in the Post-PHV vs Pre-PHV SSG, as pre-PHV (5.10 ± 1.00 AU) players reported a significantly greater RPE than post-PHV (4.16 ± 1.28 AU) players (difference 0.94 AU, ES = 0.82, $p = 0.009$, *moderate*).

On the small pitch size in the Post-PHV 1 vs Post-PHV 2 SSG both teams reported an identical mean RPE (4.83 ± 0.74 AU, ES = 0, $p = 1.000$, *trivial*). Irrespective of SSG type (Post-PHV 1 vs Post-PHV 2; Post-PHV vs Pre-PHV; Pre-PHV 1 vs Pre-PHV 2), post-PHV players reported their greatest mean RPE on the medium pitch condition (4.70 ± 0.85 AU) and their lowest mean RPE (4.19 ± 1.17 AU) on the expansive pitch condition. Pre-PHV players also presented their greatest mean RPE on the medium pitch condition (5.22 ± 0.95 AU), however their lowest RPE (4.53 ± 0.88 AU) was recorded on the small pitch condition.

In the mixed maturity SSGs there was a significant difference on the medium pitch size in Mixed 2 as post-PHV (4.00 ± 0.82 AU) players logged significantly lower RPE than pre-PHV (5.13 ± 0.99 AU) players (mean difference 1.13 AU, ES = 1.25, $p = 0.034$, *large*). However, on the large pitch size in Mixed 2 both the pre-PHV and post-PHV players reported equal RPE (5.00 ± 0.58 AU, ES = 0, $p = 1.000$, *trivial*). There were no other significant differences in the mixed SSGs. When viewing RPE across pitch sizes, in the mixed maturity SSGs, post-PHV players reported their greatest mean RPE on the large pitch size (5.04 AU) and their lowest mean RPE on the small pitch size (4.72 AU), likewise the pre-PHV players recorded their lowest mean RPE on the small pitch size (4.78 AU), however their greatest mean RPE was on the medium pitch size (5.46 AU).

When comparing the pre-PHV and post-PHV players in maturity matched bio-banded (Post-PHV 1 vs Post-PHV 2; Pre-PHV 1 vs Pre-PHV 2) SSGs against maturity mis-matched SSGs (Post-PHV vs Pre-PHV), post-PHV players reported a greater mean RPE on the small (4.83 ± 0.72 AU), large (5.07 ± 0.88 AU) and expansive (4.25 ± 0.97 AU) pitch sizes for the maturity matched bio-banded SSGs, compared to the maturity mis-matched SSGs (small – 4.45 ± 1.40 AU; large – 4.07 ± 0.98 AU; expansive – 4.16 ± 1.28 AU). However, in the maturity mis-matched SSGs post-PHV players reported a greater mean RPE (4.95 ± 0.89 AU) compared to the maturity matched bio-banded SSG (4.31 ± 0.63 AU), on the medium pitch size. Pre-PHV players reported a greater mean RPE during maturity mis-matched SSGs across all pitch sizes (small – 4.59 ± 0.98 AU; medium – 5.32 ± 0.83 AU; large – 4.96 ± 1.00 AU; expansive – 5.10 ± 1.00 AU), compared to the maturity matched bio-banded SSGs (small – 4.43 ± 0.65 AU; medium – 5.00 ± 1.13 AU; large – 4.47 ± 1.13 AU; expansive – 4.91 ± 0.70 AU).

4.4 dRPE-Overall (CR-100)

The scores for dRPE-Overall (CR-100), maturity matched/mis-matched banded SSGs, are presented in figures (6, 7, 8 and 9). Each figure is dissected to explain what is being displayed.

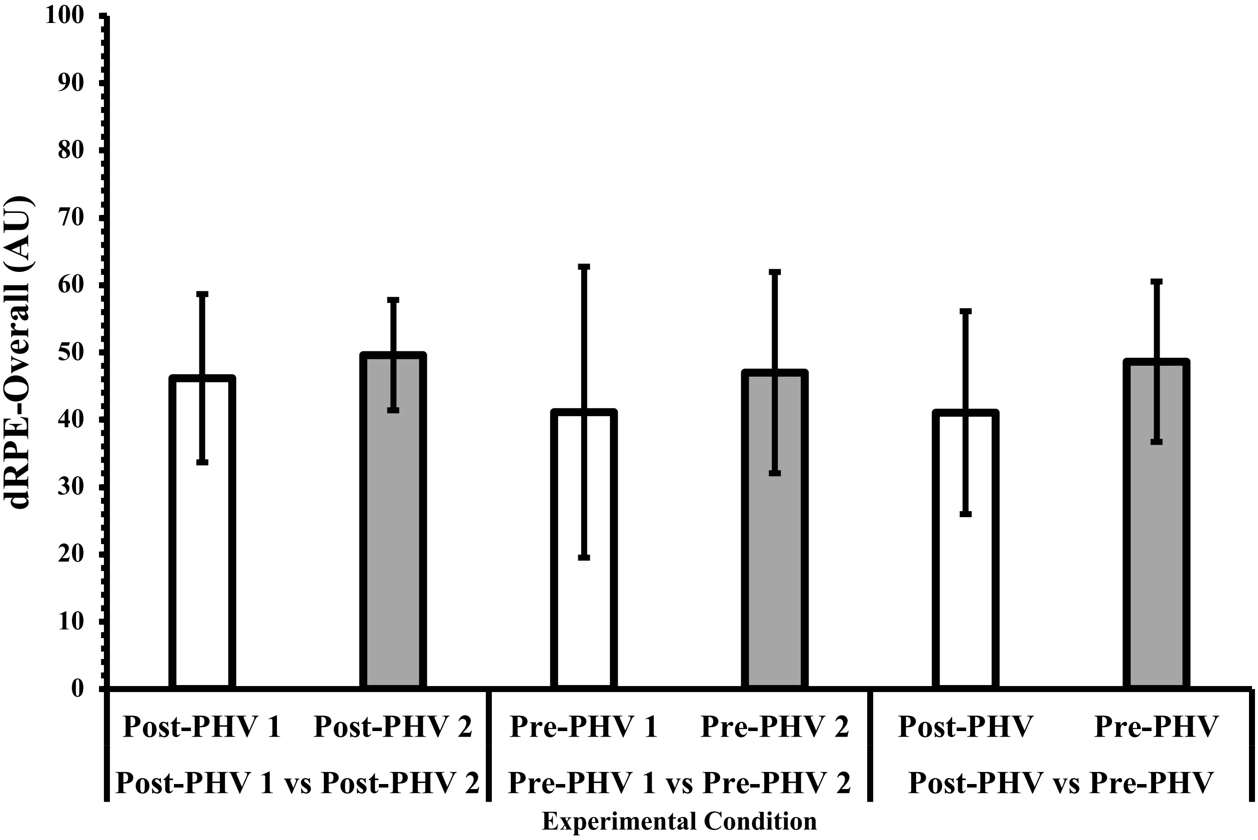

Figure 6. dRPE-Overall (CR-100) scores for the maturity matched/mis-matched banded SSGs. Small pitch size (17m x 17m). Data presented as mean ± SD.

During the small pitch size condition, Post-PHV 1 vs Post-PHV 2 (mean difference 3.43 AU, ES = 0.33, *p = 0.612, small*), Post-PHV vs Pre-PHV (mean difference 7.57 AU, ES = 0.56, *p = 0.056, small*) and Pre-PHV 1 vs Pre-PHV 2 (mean difference 5.87 AU, ES = 0.32, *p = 0.580, small*) showed no significant differences in dRPE-Overall. There were no significant differences (Mixed 1, ES = 0.19, *p = 0.523*; Mixed 2, ES = 0.07, *p = 0.885*, Mixed 3, ES = 0.00, *p = 0.997*) in the mixed maturity SSGs and all effect sizes were *trivial*.

When comparing the pre- and post-PHV players in maturity matched bio-banded (Post-PHV 1 vs Post-PHV 2; Pre-PHV 1 vs Pre-PHV 2) SSGs against maturity mis-matched SSGs (Post-PHV vs Pre-PHV), pre-PHV players reported a greater mean dRPE-Overall in maturity mis-matched SSGs (48.62± 11.91 AU) compared to maturity matched bio-banded SSGs (43.64 ± 18.62 AU). Conversely, post-PHV players reported a greater mean dRPE-Overall for the maturity matched bio-banded SSGs (47.73 ± 10.40 AU), compared to the maturity mis-matched SSGs (41.05 ± 15.07 AU).

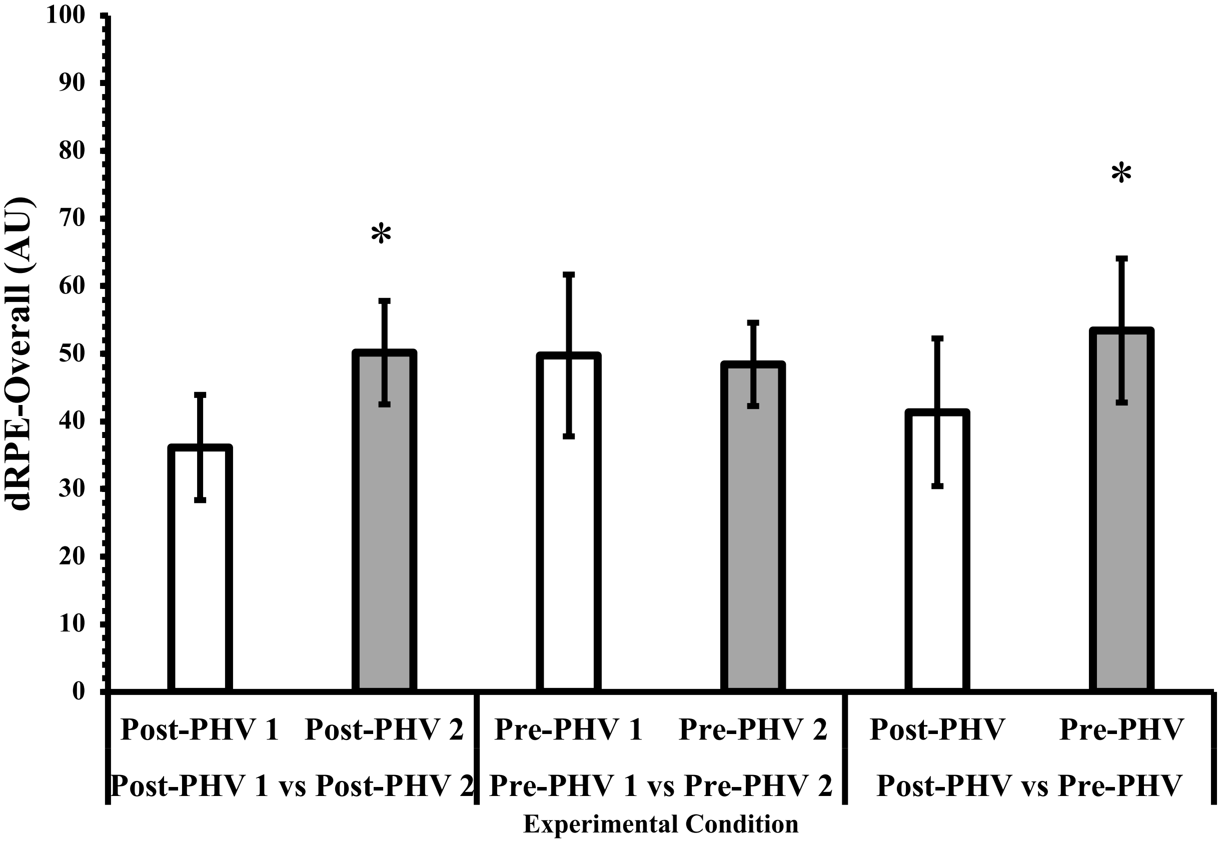

Figure 7. dRPE-Overall (CR-100) scores for the maturity matched/mis-matched banded SSGs. Medium pitch size (24m x 24m). Data presented as mean ± SD. * shows significance at the 0.05 level.

During the medium pitch condition, Post-PHV 1 vs Post-PHV 2 (mean difference 14.03 AU, ES = 1.82, *p = 0.008, large*) and Post-PHV vs Pre-PHV (mean difference 12.09 AU, ES = 1.12, *p = 0.001, moderate*) displayed a significant difference in dRPE-Overall. However, Pre-PHV 1 vs Pre-PHV 2 (mean difference 1.32 AU, ES = 0.15, *p = 0.811, trivial*) did not show a significant difference. Despite there being no significant differences in the dRPE-Overall in the mixed maturity SSGs, the effect sizes ranged from *small* to *large* in Mixed 1 (ES = 0.31, *p = 0.320, small*) Mixed 2 (ES = 0.66, *p = 0.250, moderate*) and Mixed 3 (ES = 1.20, *p = 0.064, large*).

When comparing the pre- and post-PHV players in maturity matched bio-banded (Post-PHV 1 vs Post-PHV 2; Pre-PHV 1 vs Pre-PHV 2) SSGs against maturity mis-matched SSGs (Post-PHV vs Pre-PHV), pre-PHV players reported a greater mean dRPE-Overall in maturity mis-matched SSGs (53.44 ± 10.65 AU) compared to maturity matched bio-banded SSGs (48.91 ± 8.13 AU). Conversely, post-PHV players reported a greater mean dRPE-Overall for the maturity matched bio-banded SSGs (42.62 ± 10.37 AU), compared to the maturity mis-matched SSGs (41.35 ± 10.92 AU).

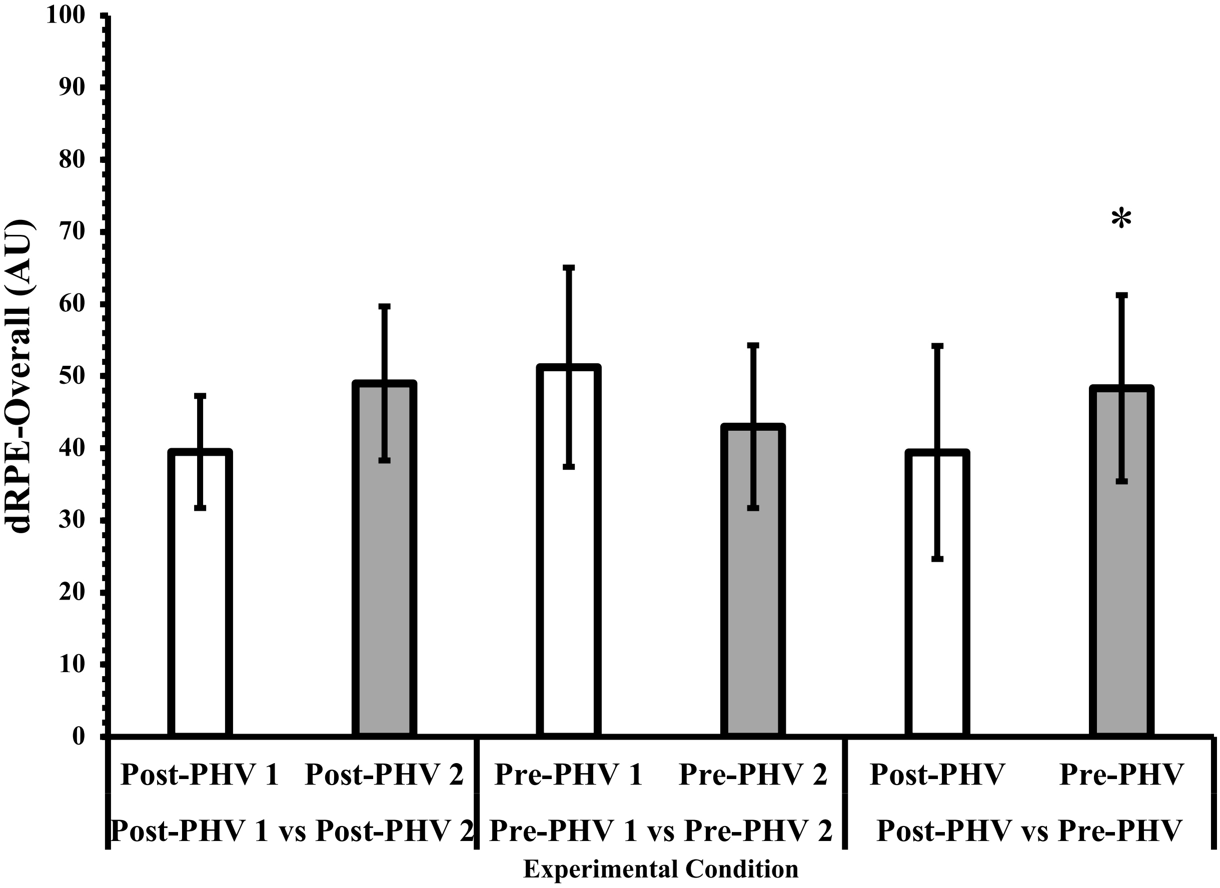

Figure 8. dRPE-Overall (CR-100) scores for the maturity matched/mis-matched banded SSGs. Large pitch size (29.5m x 29.5m). Data presented as mean ± SD. * shows significance at the 0.05 level.

During the large pitch condition Post-PHV 1 vs Post-PHV 2 (mean difference 9.50 AU, ES = 1.03, *p = 0.099, moderate*) and Pre-PHV 1 vs Pre-PHV 2 (mean difference 8.25

AU, ES = 0.66, *p = 0.232, moderate*) did not show any significant difference in dRPE-Overall. However, Post-PHV vs Pre-PHV (mean difference 8.90 AU, ES = 0.64, *p = 0.021, moderate*) showed a significant difference in dRPE-Overall. In the mixed maturity SSGs, there was no significant difference (Mixed 1, ES = 0.01, *p = 0.963*; Mixed 2, ES = 0.41, *p = 0.467*; Mixed 3, ES = 0.44, *p = 0.490*) on the large pitch size with effect sizes ranging from *trivial* to *small*.

When comparing the pre- and post-PHV players in maturity matched bio-banded (Post-PHV 1 vs Post-PHV 2; Pre-PHV 1 vs Pre-PHV 2) SSGs against maturity mis-matched competition (Post-PHV vs Pre-PHV), pre-PHV players reported a greater mean dRPE-Overall in maturity mis-matched SSGs (48.33 ± 12.91 AU) compared to maturity matched bio-banded SSGs (47.40 ± 12.97 AU). Conversely, post-PHV players reported a greater mean dRPE-Overall for the maturity matched bio-banded SSGs (44.62 ± 10.32 AU), compared to the maturity mis-matched SSGs (39.43 ± 14.77 AU).

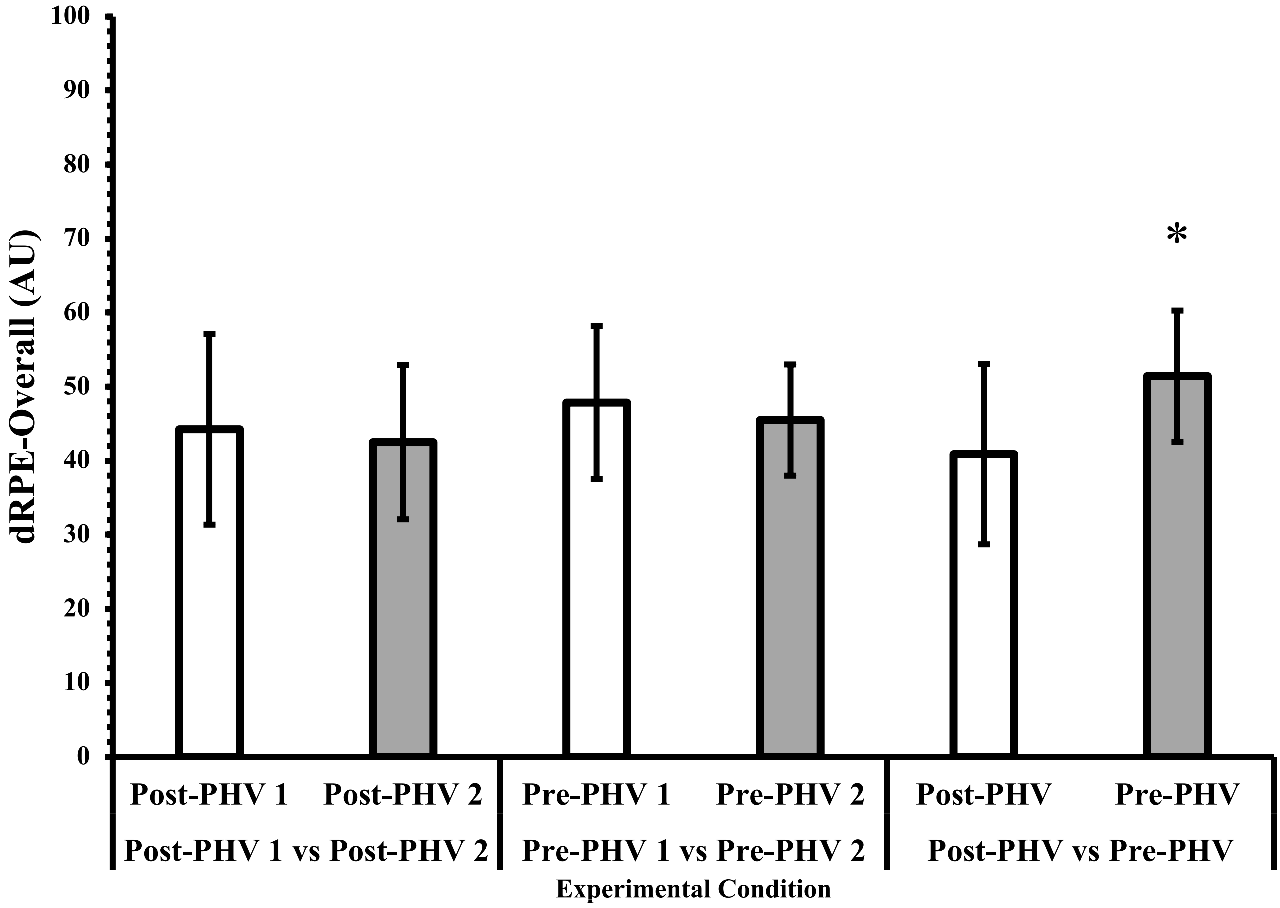

Figure 9. dRPE-Overall (CR-100) scores for the maturity matched/mis-matched banded SSGs. Expansive pitch size (34m x 34m). Data presented as mean ± SD. * shows significance at the

During the expansive pitch condition Post-PHV 1 vs Post-PHV 2 (mean difference 1.75 AU, ES = 0.15, $p = 0.819$, *trivial*) and Pre-PHV 1 vs Pre-PHV 2 (mean difference 2.36 AU, ES = 0.26, $p = 0.701$, *small*) did not show any significant difference in dRPE-Overall. However, Post-PHV vs Pre-PHV (mean difference 10.55 AU, ES = 1.00, $p = 0.002$, *moderate*) showed a significant difference in dRPE-Overall. In the mixed maturity SSGs, there was a significant difference reported in Mixed 1, on the expansive pitch size as post-PHV players reported a significantly lower dRPE-Overall (47.91 ± 8.62 AU), compared with pre-PHV players (52.82 ± 8.20 AU) (mean difference 4.91 AU, ES = 0.58, $p = 0.045$, *small*). There was also a *moderate* effect size found in Mixed 3, despite there being no significant difference in dRPE-Overall (ES = 0.87, $p = 0.164$, *moderate)*.

When comparing the pre- and post-PHV players in maturity matched bio-banded (Post-PHV 1 vs Post-PHV 2; Pre-PHV 1 vs Pre-PHV 2) SSGs against maturity mis-matched SSGs (Post-PHV vs Pre-PHV), post-PHV players reported a greater mean dRPE-Overall for the maturity matched bio-banded SSGs (43.67 ± 11.66 AU), compared to the maturity mis-matched SSGs (40.88 ± 12.17 AU). On the other hand, pre-PHV players reported a greater mean dRPE-Overall in maturity mis-matched SSGs (51.43 ± 8.86 AU) compared to maturity matched bio-banded SSGs (47.00 ± 9.09 AU).

4.5 dRPE-B (CR-100)

There were no significant differences in dRPE-B in both the maturity matched/mis-matched bio-banded and mixed maturity SSGs across all pitch sizes.

In the maturity matched/mis-matched banded SSGs, the effect size ranged from *trivial* to *large*. In the Post-PHV vs Pre-PHV SSGs, the effect size remained as *small* throughout the pitch sizes, with the mean difference 4.02 AU, 5.11 AU, 1.43 AU, 6.27 AU in the small, medium, large and expansive pitch sizes, respectively. In the Post-PHV vs Pre-PHV SSGs on the small pitch size post-PHV players reported greater dRPE-B than pre-PHV players, however the difference was insignificant (mean difference 4.02 AU, ES = 0.27, $p = 0.352$, *small*). The *large* effect size was witnessed on the expansive pitch size in the Pre-PHV 1 vs Pre-PHV 2 SSG (mean difference 11.00 AU, ES = 1.27, $p = 0.060$). In the mixed maturity SSGs, the effect sizes ranged from *trivial* to *small*.

When comparing the pre- and post-PHV players in maturity matched bio-banded (Post-PHV 1 vs Post-PHV 2; Pre-PHV 1 vs Pre-PHV 2) SSGs against maturity mis-matched SSGs (Post-PHV vs Pre-PHV), post-PHV players reported a greater mean dRPE-B for the maturity matched bio-banded SSGs across all pitch sizes (small – 44.75 ± 14.89 AU; medium – 48.23 ± 10.11 AU; large – 50.00 ± 11.86 AU; expansive – 43.92 ± 12.46 AU) compared to maturity mis-matched SSGs (small – 43.50 ± 14.40 AU; medium – 42.45 ± 14.73 AU; large – 41.21 ± 16.18 AU; expansive – 38.68 ± 14.62 AU), across all pitch sizes. On the other hand, pre-PHV players reported a greater mean dRPE-B in maturity mis-matched SSGs on the small (39.48 ±14.91 AU), medium (47.56 ± 13.97 AU) and expansive pitch sizes (44.95 ± 12.19 AU), compared to the maturity matched bio-banded SSGs (small – 44.75 ± 14.89 AU; medium – 48.23 ± 10.11 AU; expansive – 43.92 ± 12.46 AU). However, on the large pitch size, pre-PHV players reported a greater mean dRPE-B in the maturity matched bio-banded SSGs (42.73 ± 19.82 AU), compared to the maturity mis-matched SSGs (42.64 ± 14.18 AU).

4.6 dRPE-L (CR-100)

There was no significant difference in the small, medium and large pitch sizes in the banded SSGs, however on the expansive pitch size there was a significant difference as pre-PHV (43.52 ± 12.44 AU) players reported a significantly greater leg muscle exertion than post-PHV (33.64 ± 11.64 AU) players (Post-PHV vs Pre-PHV) (mean difference 9.88 AU, ES = 0.82, *moderate, p = 0.008*). There was no significant difference reported in the mixed maturity SSGs. The effect sizes ranged from *trivial* to *moderate.* The *moderate* effect size was found in Mixed 2 on the expansive pitch size (mean difference 0.39, ES = 1.04, *p = 0.073*).

When comparing the pre- and post-PHV players in maturity matched bio-banded (Post-PHV 1 vs Post-PHV 2; Pre-PHV 1 vs Pre-PHV 2) SSGs against maturity mis-matched SSGs (Post-PHV vs Pre-PHV), post-PHV players reported a greater mean dRPE-L, across all pitch sizes, in maturity matched bio-banded SSGs (small – 38.75 ±

12.82 AU; medium – 43.08 ± 11.62 AU; large – 43.79 ± 13.83 AU; expansive – 37.67 ± 11.79 AU), compared to maturity mis-matched SSGs (small – 36.15 ± 15.84 AU; medium – 37.90 ± 9.75 AU; large – 33.14 ± 10.36 AU; expansive – 33.64 ± 11.64 AU). Pre-PHV players, similarly, reported a greater mean dRPE-L in the maturity matched bio-banded SSGs on the small (41.29 ± 21.01 AU) and medium (45.25 ± 9.01 AU) pitch sizes, compared to the maturity mis-matched SSGs (small – 37.90 ± 13.44 AU; medium – 43.64 ± 14.55 AU). However, pre-PHV players reported a greater mean dRPE-L in the maturity mis-matched SSGs on the large (40.43 ± 17.53 AU) and expansive (43.52 ± 12.44 AU) pitch sizes, compared to the maturity matched bio-banded SSGs (large – 38.53 ± 16.59 AU; expansive 43.45 ± 9.27 AU).

4.7 dRPE-T (CR-100)

The ratings for dRPE-T (CR-100), maturity matched/mis-matched bio-banded SSGs, are presented in figures (10, 11, 12 and 13). Each figure displays across fixture differences, as well as the differences between bio-banded teams within maturity matched/mis-matched bio-banded SSGs.

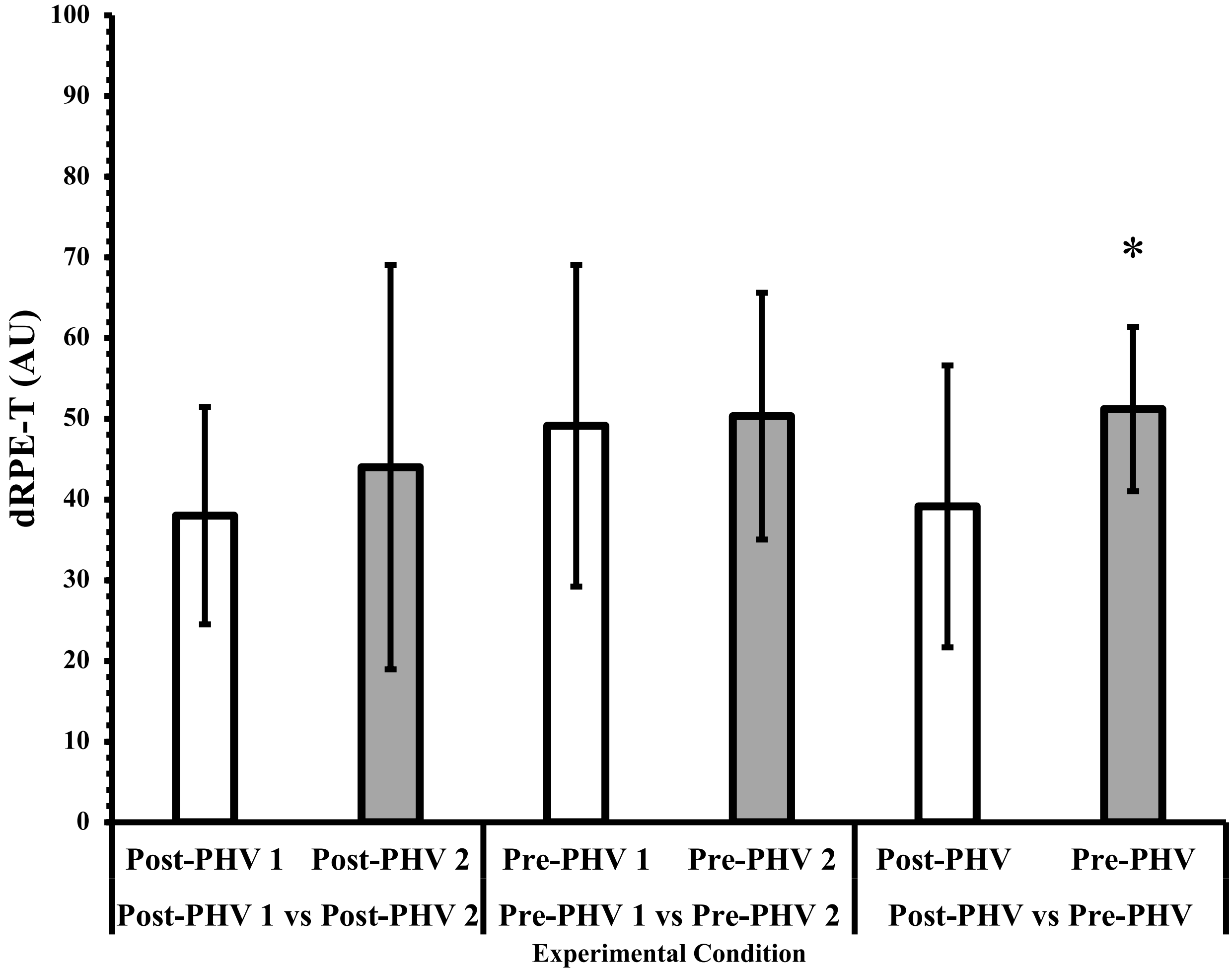

Figure 10. dRPE-T (CR-100) scores for the maturity matched/mis-matched banded SSGs. Small pitch size (17m x 17m). Data presented as mean ± SD. * shows significance at the 0.05 level.

During the small pitch size condition Post-PHV 1 vs Post-PHV 2 (mean difference 6.00 AU, ES = 0.31, *p = 0.617, small*) and Pre-PHV 1 vs Pre-PHV 2 (mean difference 1.20 AU, ES = 0.07, *p = 0.904, trivial*) did not show any significant difference in dRPE-T. However, Post-PHV vs Pre-PHV showed a significant difference in dRPE-T (mean difference 12.06 AU, ES = 0.87, *p = 0.004, moderate*). In the mixed maturity SSGs there were no significant differences reported. The effect size extended from *trivial* to *moderate.* The *trivial* effect size was witnessed in Mixed 3 (mean difference 0.69 AU, ES = 0.05, *p = 0.934*). The *moderate* effect size was in Mixed 2 (mean difference 9.88 AU, ES = 0.82, *p = 0.157*).

When comparing the pre- and post-PHV players in maturity matched bio-banded (Post-PHV 1 vs Post-PHV 2; Pre-PHV 1 vs Pre-PHV 2) SSGs against maturity mis-matched SSGs (Post-PHV vs Pre-PHV), post-PHV players recorded a greater mean dRPE-T in the maturity matched bio-banded SSGs (41.00 ± 19.43 AU), compared to the maturity mis-matched SSGs (39.15 ± 17.47 AU). Pre-PHV players, however, recorded a greater mean dRPE-T in the maturity mis-matched SSGs (51.21 ± 10.19 AU), compared to the maturity matched bio-banded SSGs (49.64 ± 17.43 AU).

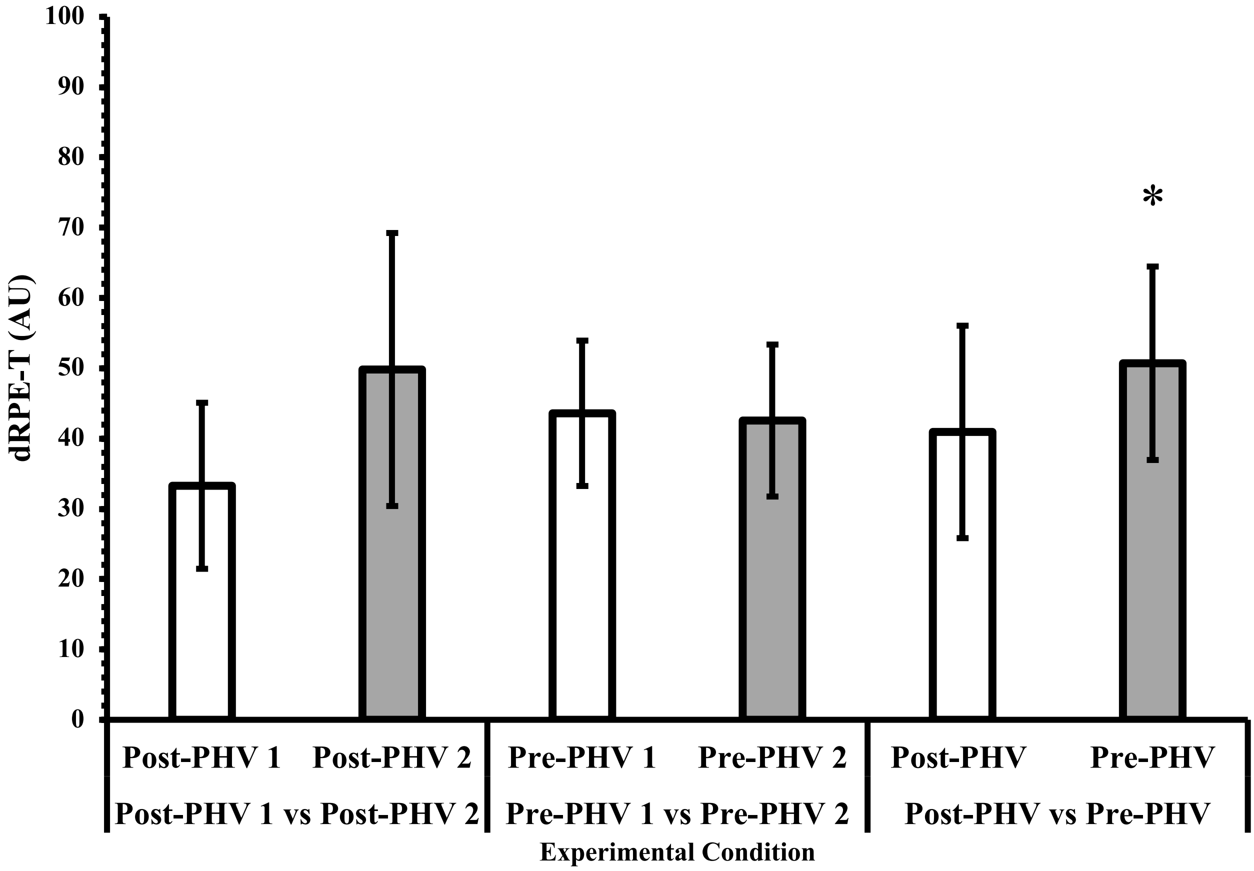

Figure 11. dRPE-T (CR-100) scores for the maturity matched/mis-matched banded SSGs. Medium pitch size (24m x 24m). Data presented as mean ± SD. * shows significance at the 0.05 level.

During the medium pitch size condition Post-PHV 1 vs Post-PHV 2 (mean difference 16.54 AU, ES = 1.06, *p = 0.085, moderate*) and Pre-PHV 1 vs Pre-PHV 2 (mean difference 1.03 AU, ES = 0.10, *p = 0.872, trivial*) did not show any significant difference in dRPE-T. However, Post-PHV vs Pre-PHV showed a significant difference in dRPE-T mean difference 9.77 AU, ES = 0.68, , *p = 0.029, moderate*). In the mixed maturity SSGs there was no significant difference reported in dRPE-T. The effect size was *small* across all SSGs. The *small* effect size across the SSGs were Mixed 1 (mean difference 3.87 AU, ES = 0.26, *p = 0.408*), Mixed 2 (mean difference 4.49 AU, ES = 0.29, *p = 0.584*), Mixed 3 (mean difference 3.17 AU, ES = 0.26, *p = 0.670*).

When comparing the pre- and post-PHV players in maturity matched bio-banded (Post-PHV 1 vs Post-PHV 2; Pre-PHV 1 vs Pre-PHV 2) SSGs against maturity mis-matched SSGs (Post-PHV vs Pre-PHV), post-PHV players recorded a greater mean dRPE-T in the maturity mis-matched SSGs (40.95 ± 15.11 AU), compared to the maturity matched bio-banded SSGs (40.92 ± 17.34 AU). Pre-PHV players also rated a greater mean dRPE-T in the maturity mis-matched SSGs (50.72 ± 13.76 AU), compared to the maturity matched bio-banded SSGs (43.00 ± 10.15 AU).

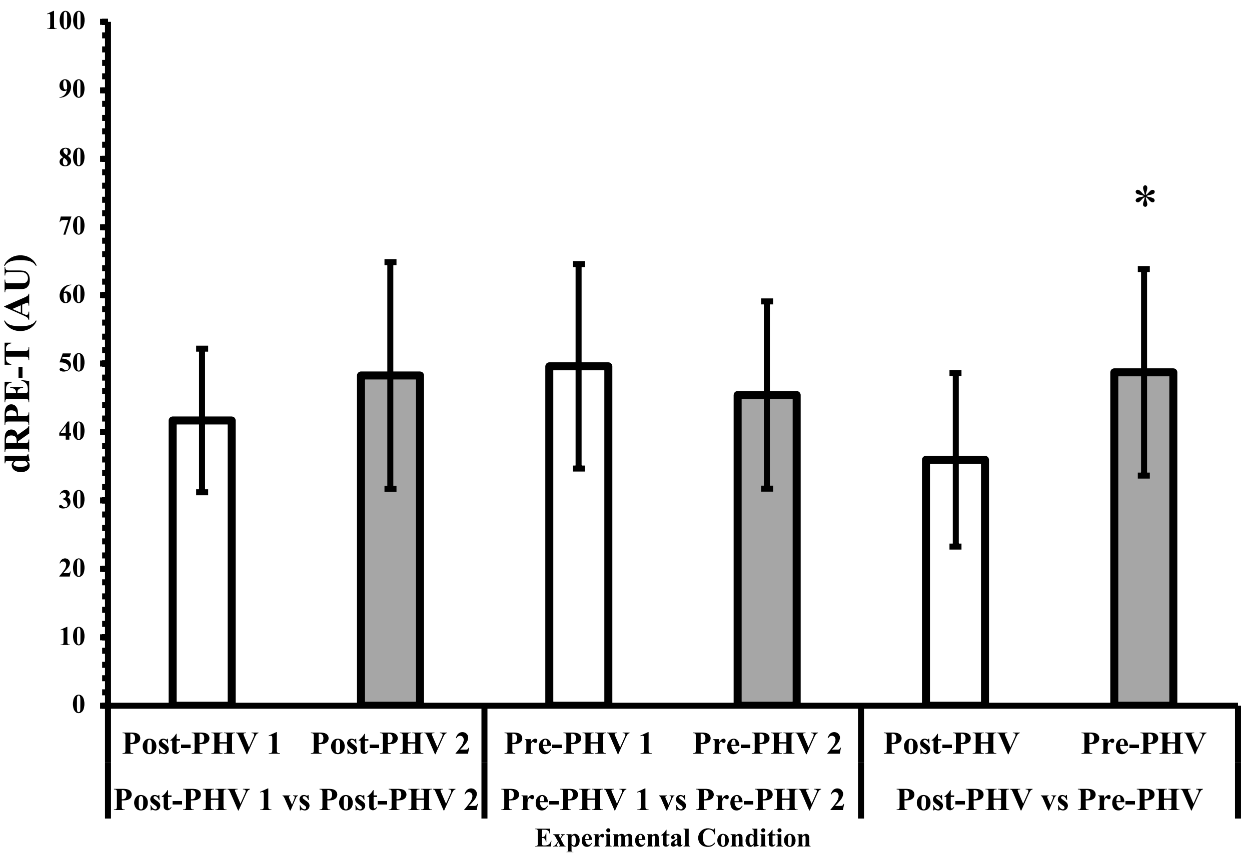

Figure 12. dRPE-T (CR-100) scores for the maturity matched/mis-matched banded SSGs. Large pitch size (29.5m x 29.5m). Data presented as mean ± SD. * shows significance at the 0.05 level.

During the large pitch size condition Post-PHV 1 vs Post-PHV 2 (mean difference 6.58 AU, ES = 0.49, *p = 0.393, trivial*) and Pre-PHV 1 vs Pre-PHV 2 (mean difference 4.20 AU, ES = 0.29, *p = 0.582, trivial*) did not show any significant difference in dRPE-T. However, Post-PHV vs Pre-PHV displayed a significant difference in dRPE-T (mean difference 12.79 AU, ES = 0.92, *p = 0.001, moderate*). In the mixed maturity SSGs no significant difference was reported, and the effect size ranged from *trivial to small.*

When comparing the pre- and post-PHV players in maturity matched bio-banded (Post-PHV 1 vs Post-PHV 2; Pre-PHV 1 vs Pre-PHV 2) SSGs against maturity mis-matched SSGs (Post-PHV vs Pre-PHV), post-PHV players recorded a greater mean dRPE-T in the maturity matched bio-banded SSGs (45.00 ± 13.76 AU), compared to the maturity mis-matched SSGs (35.96 ± 12.69 AU). Pre-PHV players, however, rated a greater mean dRPE-T in the maturity mis-matched SSGs (48.75 ± 15.10 AU), compared to the maturity matched bio-banded SSGs (47.67 ± 14.02 AU).

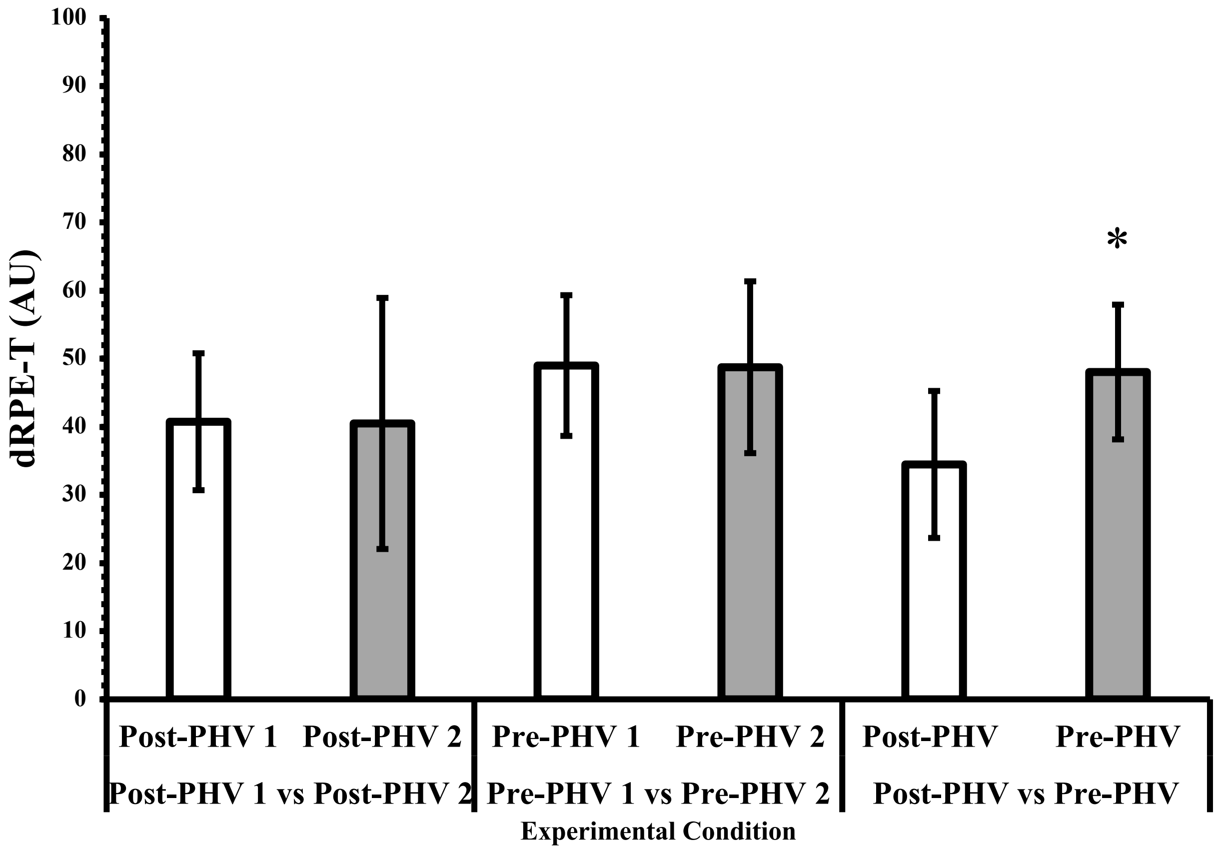

Figure 13. dRPE-T (CR-100) scores for the maturity matched/mis-matched banded SSGs. Expansive pitch size (34m x 34m). Data presented as mean ± SD. * shows significance at the 0.05 level.

During the expansive pitch size condition Post-PHV vs Pre-PHV showed a significant difference in dRPE-T (mean difference 13.57 AU, ES = 1.31, *p = 0.000, large*). In contrast, Post-PHV 1 vs Post-PHV 2 (mean difference 0.50 AU, ES = 0.02, *p = 0.976, trivial*) and Pre-PHV 1 vs Pre-PHV 2 (mean difference 0.25 AU, ES = 0.02, *p = 0.972, trivial*) did not show any significant difference in dRPE-T. In the mixed maturity SSGs no significant difference was reported. The effect size ranged from *small* to *moderate.* The *moderate* effect size was in the Mixed 2 fixture (mean difference 8.29 AU, ES = 0.67, *p = 0.218*).

When comparing the pre- and post-PHV players in maturity matched bio-banded (Post-PHV 1 vs Post-PHV 2; Pre-PHV 1 vs Pre-PHV 2) SSGs against maturity mis-matched SSGs (Post-PHV vs Pre-PHV), post-PHV players recorded a greater mean dRPE-T in the maturity matched bio-banded SSGs (40.67 ± 12.53 AU), compared to the maturity mis-matched SSGs (34.48 ± 10.79 AU). Pre-PHV players also rated a greater mean dRPE-T in the maturity matched bio-banded SSGs (48.91 ± 10.57 AU), compared to the maturity mis-matched SSGs (48.05 ± 9.89 AU).

4.8 Releases

In the maturity matched/mis-matched banded SSGs there was a significant difference in the number of releases in the Pre-PHV 1 vs Pre-PHV 2 SSG, on the medium pitch size, as pre-PHV 2 (10 ± 3 AU) made a significantly greater number of releases than pre-PHV 1 (5 ± 3 AU) (mean difference 5 AU, ES = 1.44, $p = 0.031$, *large*). Despite there being no significant difference, a *moderate* effect size was found in the Post-PHV 1 vs Post-PHV 2 SSGs on both the small (mean difference 3 AU, ES = 0.74, $p = 0.244$) and the medium (mean difference 2 AU, ES = 0.78, $p = 0.222$) pitch sizes. There were no significant differences found across the mixed maturity conditions. The effect sizes ranged from *trivial* to *moderate*. The *moderate* effect size was found in Mixed 3 on the expansive pitch size (mean difference 2 AU, ES = 0.67, $p = 0.288$). All effect sizes for the mixed maturity SSGs on the medium pitch size were *small*, and all effect sizes on the large pitch size were *trivial*.

When comparing the pre- and post-PHV players in maturity matched bio-banded (Post-PHV 1 vs Post-PHV 2; Pre-PHV 1 vs Pre-PHV 2) SSGs against maturity mis-matched SSGs (Post-PHV vs Pre-PHV), post-PHV players displayed a greater mean number of releases during maturity matched bio-banded SSGs on the small pitch size condition (9 ± 4 AU), compared to the maturity mis-matched SSGs (9 ± 2 AU). The opposite was found on the medium, large and expansive pitch sizes, as post-PHV players recorded a greater mean number of releases during maturity mis-matched SSGs (8 ± 2 AU; 8 ± 3 AU; 8 ± 3 AU, respectively), compared to maturity matched bio-banded SSGs (8 ± 3 AU; 8 ± 2 AU; 7 ± 3 AU, respectively). The pre-PHV players recorded a greater mean number of releases during the maturity matched bio-banded SSGs on the medium (8 ± 3 AU) and large (7 ± 3 AU) pitch sizes, compared to the maturity mis-matched SSGs (medium – 8 ± 4 AU; large 7 ± 4 AU). Pre-PHV players reported a greater mean number of releases during the maturity mis-matched SSGs on the small (9 ± 4 AU) and expansive (7 ± 4 AU) pitch sizes, compared to the maturity matched bio-banded SSGs (small – 7 ± 3 AU; expansive – 6 ± 3 AU).

4.9 Principal component analysis

A PCA analysis was completed for each fixture type, per pitch size (*see Methods Section, 3.4.2 Principal Component Analysis*). With the exception of Pre-PHV 1 vs Pre-PHV 2 and Mixed 3 on the medium pitch size, Post-PHV 1 vs Post-PHV 2 and Mixed 3 on the expansive pitch size, all four facets of dRPE (dRPE-Overall, dRPE-B, dRPE-L & dRPE-T) were uniform and the majority of the variance could be explained in the same principal component (PC). In the Pre-PHV 1 vs Pre-PHV 2 SSG on the medium pitch size (Table 15), dRPE-Overall could be explained in both PC1 (0.659) and PC3 (0.571), likewise dRPE-B (0.708) and dRPE-L (0.809) were explained in PC1, whereas dRPE-T (0.888) was explained within PC2. In Mixed 3 on the medium pitch size (Table 18), three of the four facets of dRPE were explained by a different principal component, dRPE-Overall (PC1; 0.942), dRPE-B & dRPE-T (PC3; 0.950 & 0.882, respectively) and dRPE-L (PC4; 0.810). On the expansive pitch size in the Post-PHV 1 vs Post-PHV

2 fixture (Table 25), dRPE was explained in two separate components as dRPE-Overall and dRPE-B (PC1; 0.785 and 0.902, respectively) were explained differently to dRPE-L and dRPE-T (PC3; 0.917 and 0.848, respectively).

As pitch size increased so did the likelihood of RPE (CR-10) and dRPE-Overall (CR-100) being categorised under the same PC. On the small pitch size there was only one incidence of the two falling under the same PC, this was witnessed in the Post-PHV 1 vs Post-PHV 2 fixture (Table 7). However, in this occurrence only part of dRPE-Overall was explained (0.423), with the largest part of RPE (CR-10) being explained (0.884). On the medium pitch size RPE (CR-10) and dRPE-Overall (CR-100) could be explained, in some part, under the same PC in four out of the six categories of fixture (Post-PHV 1 vs Post-PHV 2 (Table 13), Post-PHV vs Pre-PHV (Table 14), Mixed 1 (Table 16) and Mixed 3 (Table 18)). On the large and expansive pitch sizes RPE (CR-10) and dRPE-Overall (CR-100) overlapped within PCs across all SSGs, however in a number of these SSGs one of the variables was witnessed within some part of another PC. There was no degree of acceptance witnessed between total distance and mean heart rate falling under the same principal component, as the figures display as often as it did, it also did not. In the Mixed 1 SSG on the expansive pitch size (Table 28), releases did not fall under any of the principal components within the analysis.

The variance of the components of dRPE were analysed against each other with the aim of understanding how many occasions the facets of dRPE were classified as the same component. All four facets of dRPE (dRPE-Overall, dRPE-B, dRPE, L & dRPE-T) were classified under the same principal component in thirteen out of twenty-four occasions (54.2%). It was found that on eighteen occasions out of twenty-four (75%), dRPE-B and dRPE-L were recorded under the same principal component. This figure drops slightly to 66.6% when also viewing dRPE-T alongside dRPE-B and dRPE-L as the occurrence of all three facets of dRPE under the same principal component occurs sixteen times out of twenty-four. dRPE-Overall was categorised in the same principal component as dRPE-B in sixteen out of twenty-four times (66.6%). dRPE-Overall was categorised under the same principal component as dRPE-L in fifteen out of twenty-four (62.5%). The PCA categorised dRPE-Overall and dRPE-T under the same principal component in twenty-one out of twenty-four occasions (87.5%).

5.0 Discussion

The aims of this thesis was to examine the effect of maturity matched and mis-matched bio-banding on academy soccer players dRPE, with the secondary aim to explore the influence of relative pitch size on subsequent dRPE. The primary findings were: (1) there was a significant difference in dRPE-Technical/Tactical/Cognitive (dRPE-T) between pre- and post-PHV players, across all relative pitch sizes as pre-PHV rated a greater RPE-T compared with post-PHV players; (2) Post-PHV players consistently perceived maturity-matched bio-banded SSGs as a greater challenge, both physically (i.e. dRPE-B & dRPE-L) and cognitively (i.e. dRPE-T), compared to maturity mis-matched SSGs; (3) Significant differences between pre- and post-PHV players in dRPE-B and dRPE-L were limited to one occasion during the expansive relative pitch size condition; (4) The internal measures of load (HR) were not affected by the relative pitch size or maturity status. Overall, these findings suggest that there is technical/tactical/cognitive difference between players of different maturity status in SSGs. As well as support for the use of bio-banded training methods in youth soccer SSGs, to afford a greater physical and cognitive challenge to those advanced in maturation. Given the multifaceted nature of this thesis, results will be discussed within the areas of interest identified with the aims.

5.1 The effect of bio-banding on facets of dRPE

Measures of dRPE have been utilised to quantify an individual’s internal load in training and match-play (Weston et al., 2014). However, there has been no research into the use of dRPE within the youth soccer population. Psychological factors have been rated as significantly more important than sociological, technical/tactical and physical factors in the (de)selection of academy soccer players (Towlson et al., 2019).

In the current thesis a significant difference was established in dRPE-T across all relative-pitch sizes when the pre-PHV players competed against post-PHV players (maturity mismatched SSGs). Pre-PHV players consistently rated a significantly greater mean dRPE-T than their post-PHV counterparts ($p = 0.000$ to $p = 0.029$, ES = *moderate – large*), despite no significant difference in their performed technical load (i.e., number of releases ($p = 0.356$ to $p = 0.931$, ES = *trivial – small*). The results suggest that pre-PHV players appear to perceive greater technical/tactical/cognitive effort, compared to their post-PHV counterparts despite the performed actions being similar. Those advanced in age may be taller and stronger than their younger counterparts. Equally, with age comes greater learning experiences and greater exposure to different technical/tactical knowledge. It is also important to consider the physical advantage of early maturation, post-PHV 1 had the greatest mean stature (169.4 cm ± 7.24) and mean body-mass (53.93 kg ± 6.09), with pre-PHV 1 displaying the lowest mean stature (146.0 cm ± 12.05) and mean body-mass (38.45 kg ± 5.41). The mean difference in maturation (EASA% = 7.4), stature (17.0 cm) and body-mass (11.48 kg) between the post-PHV and pre-PHV teams may explain the differences found in the dRPE-T. The nature of academy soccer encourages post-PHV players to play to their strengths (e.g., size, speed, power), overlooking their technical and tactical development (Malina et al., 2015). Pena-Gonzalez, Fernandez-Fernandez, Cervello and Moya-Ramon (2019) reported significant differences in chronological age, stature (cm), body-mass (kg), one rep max and peak power output between post-, mid-, and pre-PHV male youth soccer players. Pena-Gonzalez et al. (2019) also reported a significant difference in 30m-sprint (s) and T-test (s) times between pre- and post-PHV soccer players, with post-PHV players performing significantly better. Mendez-Villanueva et al. (2011) suggested differences in running performance between age-matched athletes were exclusively due to differences in maturation, rather than differences in anthropometrical characteristics. Boys advanced in maturation are likely to not only be taller and heavier but perform better in physical tests as they display greater levels of strength and speed compared to pre-PHV players. However, Pena-Gonzalez et al. (2019) utilised a maturity-offset equation (Mirwald et al., 2002) to estimate PHV, and the reliability and validity of the Mirwald maturity-offset equation has been previously questioned (Malina & Koziel, 2014). This therefore raises questions regarding the accuracy of the Pena-Gonzalez et al. (2019) findings. The current study utilised %EASA (Khamis & Roche, 1994) which has been suggested as a superior method of estimating one's maturity (Parr et al., 2020; Towlson et al., 2020a). dRPE-T is a method of obtaining technical/tactical/cognitive effort, it should therefore neglect the physical effort perceived by players.

As well as physical differences between more and less mature children, cognitive and emotional differences have been reported between the youngest and the oldest children in a chronological group (Williams et al., 1970; Malina, 1994; Musch & Gronodin, 2001). As dRPE-T should not reflect the physical effort perceived by players it is important to understand the cognitive effect of advanced maturation. Within the current findings, the post-PHV players were advanced in decimal age, compared to the pre-PHV players. Previously it has been reported that post-PHV players may possess a greater technical/tactical knowledge due to their increased age and experience (Williams, 2000; Ward & Williams, 2003). Being older, therefore, would have perhaps afforded greater soccer experience and expertise to the post-PHV players which may have allowed them to employ greater tactical and technical knowledge to beat their opponent. Individuals advanced in maturation appear to be better at detecting signals, compared to less mature players (Vänttinen, Blomqvist, Luhtanen & Häkkinen, 2010; Gonçalves, Noce, Barbosa, Figueiredo & Teoldo, 2020), or they may be better skilled in ignoring less relevant signals (Vänttinen et al., 2010). Signal detection refers to one's ability to detect an intended stimulus (Gonçalves et al., 2020). One example of signal detection in soccer would be the movement or positioning of team-mates and opponents (Sternberg, 2013). Gonçalves et al. (2020) utilised the Signal Detection test using the Vienna Test System (Schuhfried, 2006) to assess signal detection. The Signal Detection test assesses long-term selective attention as well as the ability to visually discriminate appropriate signals in the presence of distracting ones.

It has been reported that players improve their ability to understand the playing environment during their maturational process, which allows them to heighten their ability to provide faster responses to changing game situations (Gonçalves et al., 2020). The post-PHV players in the current study reported significantly less dRPE-T which suggests that they did not perceive as great an effort as the pre-PHV players which adds further support, as they may have been able to ignore irrelevant cues and focus solely on the task required. Whereas, the pre-PHV players may have perceived a greater cognitive/technical/tactical effort as they were trying to interpret a greater number of irrelevant environmental cues. The claim of Gonçalves et al. (2020), in that more mature players are better skilled and faster in detecting relevant signals, is potentially true, however in the study players were grouped and competed in chronological age teams (U11's, U13's & U15's). As expected, the mean %EASA increased through the chronological age groups (U11 – 79.5% ± 1.5; U13 – 88.7% ± 2.2; U15 – 96.7% ± 2.1), which leads to the question of whether maturity impacts upon signal detection or whether it is down to age-related experiences, as the U15 squad had a mean age of over 5 years greater than the U11 squad (Gonçalves et al., 2020). It has been suggested that it may in fact be one's age that influences their tactical understanding, rather than their maturity status (Martone et al., 2016). There appears to be a perceived psychological difference between pre- and post-PHV players when competing in maturity mis-matched SSGs, however the psychological effort perceived in maturity matched bio-banded SSGs is unknown.

In the maturity mis-matched SSGs (i.e., Post-PHV vs Pre-PHV) the mean dRPE-T scores for post-PHV players, across all relative pitch sizes (small: 39.15 ± 17.47 AU; medium: 40.95 ± 15.11 AU; large: 35.96 ± 12.69 AU & expansive 34.48 ± 10.79 AU) were similar to those shown in the maturity matched bio-banded SSGs (Post-PHV 1 vs Post-PHV 2) (small – 41 ± 19.43 AU; medium - 40.92 ± 17.34 AU; large - 45 ± 13.76 AU & expansive - 40.67 ± 12.53 AU). Cumming et al. (2017b) have suggested that bio-banded competition offers a greater psychological challenge to early maturing players, compared to chronological age competition. Early maturing players reported that during bio-banded competition they were required to make decisions quicker, process information in new ways and release the ball quicker (Cumming et al., 2017b). However, the results of the current thesis suggest this may not be the case.

The current thesis was the first of its kind to employ dRPE within youth soccer, and the results suggest there appears to be very little difference in the cognitive/technical/tactical load perceptions of post-PHV players in maturity matched bio-banded SSGs, compared to maturity mis-matched SSGs. The dRPE-T ratings for the pre-PHV players in the maturity mis-matched SSGs (Post-PHV vs Pre-PHV) (small - 51.21 ± 10.19 AU; medium - 50.72 ± 13.76 AU; large - 48.75 ± 15.10 AU & expansive - 48.05 ± 9.89 AU), were similar to those reported in the maturity matched bio-banded SSGs (Pre-PHV 1 vs Pre-PHV 2) (small - 49.64 ± 17.43 AU; medium - 43 ± 10.15 AU; large - 47.67 ± 14.02 AU & expansive - 48.91 AU ± 10.57). Results here are similar to that reported by the post-PHV players in the present thesis, in that there was very little difference (Post-PHV mean difference 0.03 to 9.04; Pre-PHV mean difference 0.86 to 7.72) between the perceived cognitive/technical/tactical effort in maturity mis-matched and maturity matched bio-banded SSGs. This might be explained by the work of Cumming et al. (2018) who suggested that later maturing players may possess a psychological advantage over their earlier maturing counterparts. This is of relevance to the present study given that it appears pre-PHV players perceive the challenge of competing against those advanced in maturation, stature and body-mass as a greater challenge compared to the perceptions of post-PHV players. This may be explained by the underdog hypothesis (Gibbs, Jarvis & Dufur, 2012). The underdog hypothesis debates that to be retained within a youth sport selection programme, younger or later maturing individuals must possess and/or develop greater technical, tactical and psychological skills (Cumming et al., 2018). Younger and/or later maturing players are required to develop technical and/or tactical abilities to counteract the physical advantage afforded to those advanced in maturation (Gibbs et al., 2012; McCarthy, Collins & Court 2016; Fumarco, Gibbs, Jarvis & Rossi, 2017).

One psychological skill that may be utilised by those delayed in maturation, to increase their ability to understand their technical/tactical environment, is self-regulation. Self-regulation is the process of controlling one's thoughts, feelings and actions and converting mental abilities in physical skills (Zimmermann, 2006). By adopting self-regulation, individual's approach tasks with greater effort levels and possess higher levels of self-efficacy (Zimmermann, 2006). Perceived self-efficacy is one's belief about their capabilities to produce designated performance levels to influence events (Bandura, 1994). Self-efficacy beliefs govern four major processes: cognitive, motivational, affective and selection (Bandura, 1994). In youth soccer, self-regulation has been shown to differentiate between successful and less successful players (Toering, Elferink-Gemser, Jordet & Visscher, 2009). Players who self-regulate appear to evaluate training outcomes and reflect upon these (Toering et al., 2009).

Reflection involves analysing one's strengths and weaknesses and considering ways in which they can be developed (Toering, Jordet & Ripegutu, 2013). Elite players have reported heightened levels of reflection and effort (Toering et al., 2009). When referring to the current thesis, this may partially explain the amount of variance shown in the dRPE-T scores from the post-PHV players. Despite the post-PHV players mean dRPE-T scores being less than the pre-PHV players, there was a greater distribution of scores in the post-PHV group, particularly for post-PHV 2 on the small pitch size. By employing self-regulation, the pre-PHV players may be better equipped to perceive their cognitive/technical/tactical effort compared to post-PHV players. To remain competitive within their age group, pre-PHV players may need to engage in and/or develop greater self-regulatory processes (Cumming et al., 2018). Zuber, Zibung and Conzelmann (2016) found that boys delayed in maturation possessed superior adaptive and technical skills, despite this however, later maturing player failed to progress into national or regional talent squads. By possessing a psychological advantage, the pre-PHV players may be better equipped to understand their technical and tactical effort in SSGs which is again highlighted in the variance shown in the current study between post-PHV and pre-PHV players' dRPE-T. Despite this, however, there appears to be no meaningful difference between the perceived cognitive/technical/tactical exertion between maturity mis-matched and maturity matched bio-banded SSGs in pre-PHV players. The dRPE-T findings contradict that found and discussed by previous research, so before conclusions can be made, it is important to understand if dRPE-T is informing practitioners of something different to just conventional RPE.

Despite the differences portrayed in dRPE-T between post-PHV and pre-PHV players, the PCA categorised dRPE-T within the same principal component as dRPE-Overall on twenty-one occasions, out of twenty-four (87.5%). Equally, Maughan, MacFarlane and Swinton (2021) reported 83.3% of variance in their data set was explained through two distinct principal components. The first component accounted for 72.9% of the total variance in the dataset, with the second component totalling 10.4% of the total variance (Maughan et al., 2021). When data falls under the same principal component it highlights that the variables are correlated with one another within that specific principal component (Maughan et al., 2021). Maughan et al. (2021) reported similar component loadings for sRPE (0.91), sRPE-B (0.89) and sRPE-L (0.88) under the same principal component. This supports the findings of the current thesis as 87.5% of the variance from dRPE-Overall and dRPE-T were correlated under the same principal component which suggests that the different measures of RPE may be rating the same perceptual feeling. Similar results were reported by Weaving, Marshall, Earle, Nevill and Abt (2014) as the initial component represented a balanced sum with the subsequent component contrasting internal and external loads. Weaving et al. (2014) suggested the intermittent nature of SSGs leads to a prolonged external-load component, ultimately leading to a higher internal-load response.

Despite the PCA assigning dRPE-T the same principal component as dRPE-Overall in twenty-one out of twenty-four cases (87.5%), the significant differences displayed between post-PHV and pre-PHV players, specifically within the Post-PHV vs Pre-PHV SSGs, indicate there is an effect present that may require greater examination. This is highlighted to a greater extent when you observe the differences in the maturity matched bio-banded SSGs (Post-PHV 1 vs Post-PHV 2 & Pre-PHV 1 vs Pre-PHV 2). Within the maturity matched bio-banded SSGs, there was no significant difference reported in dRPE-T in either the Post-PHV 1 vs Post-PHV 2 or Pre-PHV 1 vs Pre-PHV 2 SSGs ($p = 0.085$ to $p = 0.976$, ES = *trivial – moderate*). There was also no significant difference in dRPE-T between post-PHV and pre-PHV players in the mixed maturity SSGs ($p = 0.096$ to $p = 0.934$, ES = *moderate – trivial*). The findings are similar to Casamichana and Castellano (2015) who reported no correlation between RPE and external load, except for a small correlation in PlayerLoad^{TM}, in soccer. During SSGs the load measures appear to account for a similar amount of the variance explained by a single component, therefore a single training load measure may be adequate to monitor training load (Weaving et al., 2014; Maughan et al., 2021). Alternatively, Casamichana and Castellano (2015) suggested that due to the low correlations reported in their research, a range of indicators may be required to best understand training load. The PCA, in the current thesis, suggests that although significant differences were reported between post-PHV and pre-PHV players, it may in fact not be informing practitioners of anything more than general RPE. As well as dRPE-T, the thesis was interested in the use of the physical facets of dRPE (dRPE-B & dRPE-L).

Despite the forementioned limitations, dRPE may be able to discriminate between feelings of breathlessness and muscular fatigue (Lennon, 2020). In the current thesis, however, dRPE-B displayed no significant differences between pre- and post-PHV players across all pitch conditions. dRPE-L displayed a significant difference between pre- and post-PHV players on one occasion on the expansive pitch size with the pre-PHV players recording a significantly greater dRPE-L (43.52 ± 12.44 AU) than the post-PHV players (33.64 ± 11.64 AU) (mean difference 9.88 AU, ES = 0.82, $p = 0.008$, *moderate*). MacPherson et al. (2019) reported no significant difference between dRPE-B, dRPE-L & dRPE-T in semi-professional soccer players (23.7 ± 4.5 years) across seven consecutive training sessions. The results of which offers support for the current thesis. MacPherson et al. (2019) was able to show sessional differences in the varying facets of dRPE, whereas the current thesis exhibited no significant mean difference across relative pitch conditions. This may be due to the differences in sessional training RPE collection and RPE collected from SSGs alone. One rationale for a lack of difference between the facets, as reported in previous research and the current thesis, were that the training sessions were a concoction of physical, technical and tactical training (MacPherson et al., 2019). This type of training reveals the absence of a dominant sensory output, as per McLaren et al. (2017) who focussed solely upon a physical training programme and found significant differences. In the current thesis the pitch dimensions were altered, with the rules and means of scoring remaining consistent, however, in MacPherson et al. (2019) the coach planned the session as they saw fit which led to the classification of seven drill types from SSGs to set piece drills. The different drills incorporated into the coaches training sessions may explain the sessional differences reported in MacPherson et al. (2019), that were not evident in SSGs only, in the current thesis.

Previous research has also found clear and large differences between dRPE-B and dRPE-L, suggesting they represent different measurements of effort (Weston et al., 2014; McLaren et al., 2016). dRPE-B appears to reflect central feelings (e.g., the uptake of oxygen), whereas dRPE-L appears to reflect more peripheral feelings (e.g., neuromuscular and musculoskeletal) (Millet, Vleck & Bentley, 2009). The opposite is highlighted through the PCA within the current thesis, evidenced by eighteen occasions out of twenty-four (75%), it was found that both dRPE-B and dRPE-L were recorded under the same principal component. When observing dRPE-T alongside dRPE-B and dRPE-L, the three facets were categorised under the same principal component in sixteen out of twenty-four occasions (66.6%). This suggests that they are collecting the same information and not providing the practitioner with unique information. This was perhaps because the SSGs did not allow for a dominant sensory input (MacPherson et al., 2019), meaning the youth athletes were unable to effectively differentiate feelings of breathlessness with feelings of leg-muscle fatigue. To further express this, within the PCA of the six occasions in which dRPE-B and dRPE-L do not directly fall under the same PCA, they do overlap in four with part of the dRPE scores falling under the same principal component as the other.

Towlson et al. (2020b) reported a greater sRPE-TL in pre-PHV players in mis-matched bio-banded SSGs, despite no meaningful difference in mean HR. This is significant, as it suggests the greater sRPE may be attributed to something other than physical internal load, as displayed by no difference in mean HR. Towlson et al. (2020b) attributed the finding to pre-PHV players perhaps perceiving a different facet (e.g., technical, tactical, cognitive) of performance as effort. There is added weight to the suggestion by Towlson et al. (2020b) as in the current thesis pre-PHV players reported a significantly greater dRPE-T than post-PHV players in all maturity mis-matched SSG's. Charlot, Zongo, Leicht, Hue and Galy (2016) reported increased RPE, using the Foster et al. (2001) CR-10 scale, during game 3 out of 4 of a Futsal tournament. However, HR was similar with the previous games, a similar phenomenon was found by Rodriguez-Marroyo, Villa, Garcia-Lopez and Foster (2012) as they found that cyclists reported increased RPE over several days of racing, whilst HR remained constant. The suggestion is that the increased RPE was attributed to muscular fatigue, as HR remained constant (Martin & Anderson, 2000; Halson, 2014). Despite the findings of the PCA, there is a case to support the usefulness of dRPE as it can allow an athlete to detach sensations from different parts of their body. Differential ratings of perceived exertion allow for more than just the separation of physical sensations, it allows for an individual to rate their perceptions of cognitive exertion. McLaren et al. (2017) reported sRPE-B, sRPE-L, sRPE-U (session rating of perceived upper-body muscle exertion) and sRPE-T all made a unique contribution to sRPE, through a regression analysis. The input of each measure, however, is dependent on the training measure (McLaren et al., 2017).

Team-sport athletes can distinguish differences between feelings of breathlessness, upper/lower body muscular fatigue and cognitive exertion across a range of training activities with different external loads (McLaren et al., 2017). However, the findings of the current thesis suggest that in SSGs, within the youth population, dRPE may not be entirely beneficial and may only act as an extension of dRPE-Overall without informing the practitioner of anything different. Further research is required into the usefulness of dRPE within the youth population, it can be assumed, from the results of the current thesis, that dRPE-B and dRPE-L appear to be rating the same physical sensation during SSGs. Maughan et al. (2021) proposed that dRPE (dRPE-B & dRPE-L) is unnecessary in a group of youth soccer players (17.4 ± 1.3 years) and does not provide unique information compared to RPE.

5.2 The effect of bio-banding on external loads

The thesis aimed to examine how maturity matched and maturity mis-matched bio-banded small-sided games effected different training loads. The thesis found substantial support for the use of maturity matched bio-banded SSGs within youth soccer, particularly to support the development of post-PHV players. Post-PHV players were found to cover a greater mean total distance in maturity matched bio-banded SSGs, across all pitch sizes, compared to the mean total distance covered within maturity mis-matched SSGs. This is in agreement with Towlson et al. (2020b) who reported few differences in physical performance variables between the two most extremes (Pre-PHV vs Post-PHV). This finding is of relevance to the present thesis, given the same SSGs method was utilised in both studies and was based on a validated SGGs design for talent identification purposes (Fenner et al., 2016) and found consistent findings relating to external physical load metrics. However, the present thesis employed advancing relative pitch sizes (medium ($72m^2$), large ($108.8m^2$), and expansive ($144.5m^2$)) which were larger than that employed by Towlson et al. (2020b) ($52.6m^2$), but the small pitch condition ($36.1m^2$) was smaller. The relative pitch sizes may explain the similar and different results in both studies, as in the current thesis there was no meaningful difference found in total distance covered between pre- and post-PHV players on the small (ES = 0.47, $p = 0.115$, *small*) or medium (ES = 0.52, $p = 0.102$, *small*) pitch conditions. This supports that of Towlson et al. (2020b), however a significant difference was found on the large pitch condition (ES = 0.78, $p = 0.006$, *moderate*). There was also no meaningful difference found on the expansive pitch condition in the maturity mis-matched SSG (, ES = 0.34, $p = 0.328$, *small*).

It has been suggested that larger pitches stimulate greater physical demands and allow for greater running speeds (Owen et al., 2004). However, Abbott et al. (2019) reported little difference in physical performance metrics (i.e., total distance (m), high-speed running distance (m)) in bio-banded full-match play (11 vs. 11 - 100 x 64m - $290.9m^2$, per player) of a longer duration. Abbott et al., (2019) utilised boys within the 85-90% predicted adult height maturation band, however the participants in the current thesis ranged between 80% and 96% EASA. The current thesis involved 19 boys 90% EASA or greater, which would have excluded them from the sample of players in Abbott et al., (2019). The different bandings used may explain the differences reported in the current thesis and the results found in Abbott et al. (2019) as the larger differences between the bandings may explain the greater differences shown in the physical output. It has been documented previously the differences in physical performance tests between those advanced in maturation, compared to those delayed in maturation (Pena-Gonzalez et al., 2019). This, in turn, may have influenced the RPE displayed by both post-PHV and pre-PHV players. The smaller range of banding in Abbott et al., (2019) may not elicit as large a difference, compared to the banding in the current thesis. By employing a wider inclusion criterion banding, the current thesis was able to display greater differences between those of advanced/delayed maturity. In the current thesis, from the players currently playing in the U13 age group, the %EASA ranged from 81.74 to 92.63 which highlights the vast maturational differences that may be evident within chronological age groups. Maturation explained a greater proportion of age-related differences in running performance, compared to age and body dimensions (Mendez-Villanueva et al., 2011; Buchheit & Mendez-Villanueva, 2014), which further highlights the above point from the current thesis. When observing players of the same chronological age group (Under – 15's) it was found that more mature players were largely older, largely taller and heavier than their less mature counterparts (Buchheit & Mendez-Villanueva, 2014). More mature players displayed moderately faster maximal sprinting, slightly faster maximal aerobic speed and, in games, showed slightly greater distance > 16 km h^{-1} and reached a slightly faster peak speed (Buchheit & Mendez-Villanueva, 2014). More mature players also performed moderately more high intensity actions and more repeated high intensity actions (Buchheit & Mendez-Villanueva, 2014). However, there was no difference in total distance covered (Buchheit & Mendez-Villanueva, 2014). This is relevant to the current thesis as unlike Towlson et al. (2020b), a significant difference was reported in mean total distance covered between pre- and post-PHV players on the large pitch condition. The differences between the studies may be attributed to the initial design as Buchheit and Mendez-Villanueva (2014) assessed maturational differences in a single chronological age group, whereas the current thesis and Towlson et al. (2020b) used a bio-banded design, including players across different chronological age groups. This may explain the differences, as using players from a range of chronological age groups, in a bio-banded design, potentially allows for greater maturational differences between athletes.

The research (Buchheit & Mendez-Villanueva, 2014) acknowledged the limitations of using a maturity offset equation (Mirwald et a., 2002), however argued the use of maturation as a measure of one's biological development has a greater impact upon physical performances than body dimensions or decimal age alone. Previous research has found that jogging (5.8 – 11.5 km.h^{-1}), running (11.5 – 15.8 km.h^{-1}) and high-speed distance (15.8 – 20 km.h^{-1}) were reduced during bio-banded competition compared to chronological age competition (Romann et al., 2020). Romann et al. (2020) reported less mean time with possession of the ball, and a greater number of unsuccessful passes, despite the mean number of passes remaining the same, during bio-banded competition. One rationale may be the size of the area and the game format adopted by Romann et al. (2020). In the research, eight 20-minute matches were played on two natural grass pitches (55 x 58m) with games one and four bio-banded and games two and three chronological age competition (U13 vs U14). The games were competed with an unspecified number of players. Fatigue may have played a role in a lower mean distance covered in bio-banded competition as the second bio-banded SSG was the last 20-minute game. In the current thesis, fatigue may also have been an issue as due to the SSG format, on several occasions certain teams had to play back-to-back without an assigned rest period in between and this may have impacted upon their match running performance and in turn, their dRPE. Romann et al. (2020) utilised an unknown maturity offset equation which displays considerable limitations, especially for those furthest removed from their aPHV (Malina & Koziel, 2014). aPHV was often underestimated in younger age groups and overestimated in older age groups in the Mirwald (Mirwald et al., 2002) equation (Malina & Koziel, 2014). As the current thesis utilised the Khamis-Roche method (Khamis & Roche, 1994) to acquire %EASA comparisons between the maturity groups may be difficult to obtain. The research (Romann et al., 2020) also involved two female participants, which must be considered due to the physiological differences displayed between males and females. Innate physiological differences have been displayed between men and women in a number of settings including the laboratory (Kang & Chaloupka, 2002; Billaut, Giacomoni & Falgairette, 2003) and the military (Daniels, Kowal, Vogel & Stayffer, 1979; Knapik et al., 2001; Yanovic et al., 2008), showing a physical advantage afforded to males based on gender alone.

5.3 The effect of bio-banding on internal loads

The present thesis showed that post-PHV players consistently rated the maturity matched bio-banded SSGs as a greater perceived challenge than the maturity mis-matched SSGs, across the small, large and expansive pitch conditions, on the CR-10 and CR-100 (dRPE-Overall, dRPE-B, dRPE-L, dRPE-T). The only exception was on the medium pitch condition whereby RPE (CR-10) and dRPE-T (CR-100) displayed a greater mean for the maturity mis-matched competition. Abbott et al. (2019) found similar results as early maturing players (post-PHV) produced a significantly greater RPE during bio-banded competition (maturity matched), compared to chronological competition (maturity mis-matched). The greater RPE exhibited by the early maturing players in bio-banded competition is likely attributed to a greater perceived physical challenge, competing against other early maturing individuals (Abbott et al., 2019). The physical advantages post-PHV players possess over pre-PHV players (e.g., greater stature, increased body-mass) are no longer available or less pronounced in maturity matched bio-banded SSGs.

Buchheit & Mendez-Villanueva (2014) reported that early maturing players consistently outperformed late maturing players in chronological age competition. Bio-banded competition exposed early maturing players to similar challenges typically faced by late maturing players in chronological competition (Abbott et al., 2019). Cumming et al. (2018) found that early maturing players described bio-banded competition as a superior physical challenge to that experienced in chronological competition. In the current thesis dRPE showed post-PHV players reported a greater dRPE-L in maturity matched bio-banded SSGs compared to maturity mis-matched SSGs across all pitch sizes. This is of significance to the present thesis as post-PHV players also covered a greater mean total distance in maturity matched bio-banded SSGs. This may be due to them competing against players of similar maturation, with a greater physical equality, the players may have had to perform at a higher intensity, and cover a greater total distance, to create goal scoring opportunities. Abbott et al. (2019) attributed greater RPE scores to a greater perceived physical challenge in early maturing players, and this may be true in part, however, the results of the current thesis may suggest the influence of a greater perceived cognitive effort experienced by post-PHV players in maturity matched bio-banded SSGs may be a factor. As post-PHV players compete against other post-PHV players they may have to execute an alternative playing style (e.g., more passing, less dribbling) than they use in chronological competition. This is indicated in the current thesis as post-PHV players reported a greater mean dRPE-T in the maturity matched bio-banded SSGs on the small, large and expansive pitch conditions, compared to the maturity mis-matched SSGs.

Pre-PHV players consistently rated the maturing mis-matched SSGs as a greater perceived challenge than the maturity matched bio-banded SSGs on the CR-10 and CR-100 (dRPE-Overall). Despite a few irregularities, when observing the three separate facets of dRPE (dRPE-B, dRPE-L & dRPE-T), the common consensus from the pre-PHV players were that the maturity mis-matched SSGs were perceived as the greater challenge physically and cognitively, compared to the maturity matched bio-banded SSGs. This is supported further as the pre-PHV players recorded a greater mean total distance covered in the maturity mis-matched SSGs on the small, medium, and large pitch conditions. Towlson et al. (2020b) showed that pre-PHV (< 87% EASA) players reported a greater mean s-RPE during maturity mis-matched SSGs, compared to maturity matched bio-banded SSGs, despite there being no meaningful difference in internal load (e.g., mean HR). Towlson et al. (2020b) argued the difference in RPE maybe due to a greater perceived psychological load, which could not be differentiated through just one rating of RPE. The advantage of maturity matched bio-banded competition for pre-PHV players is that it allows them a greater opportunity to exercise their leadership skills and to demonstrate and improve their physical abilities with players of a similar physical build (Bunce, 2019). Pre-PHV players, competing in a U.S. soccer bio-banded competition, have described the experience as less physically and technically challenging (Bunce, 2019). Despite the evidence portrayed for the use of maturity matched bio-banding, to aid the development of both pre- and post-PHV players, the thesis echo's that of previous research in that maturity matched bio-banding should not be used as a substitute of chronological competition (Abbott et al., 2019). Instead, maturity matched bio-banding should be utilised to supplement youth players development, as highlighted in this thesis, maturity matched bio-banding affords a greater physical challenge to those advanced in maturation, a challenge they do not perceive during chronological competition. Maturity matched bio-banding also offers those delayed in maturation an opportunity to utilise their physical abilities, which they may not get a chance to do when competing against those advanced in maturation.

Despite a number of authors suggesting the CR-10 and CR-100 scales can be used interchangeably (Borg, 2007; Fanchini et al., 2016) within the current thesis there were only two occasions in which both scales equally reported a significant difference. The first occasion was on the large pitch condition (Post-PHV vs. Pre-PHV – *moderate*) and the second on the expansive pitch condition (Post-PHV vs. Pre-PHV – *moderate*). However, on five separate occasions one scale reported a significant difference (*trivial-large*) whilst the other scale did not. One rationale that may be considered is the fact that the CR-100 scale was presented in tandem with the OMNI walking/running scale, whereas the CR-10 scale was presented in isolation. Previous research has suggested that category-ratio scales designed for adults host a number of limitations when used within the youth population (Bar-Or, 1977; Eston & Williams, 1986; Mahon & Marsh, 1992; Mahon, Duncan, Howe & Del Coral, 1997; Mahon, Gay & Stolen, 1998; Robertson & Noble, 1997). The pictorial-Children's Effort Rating Table (CERT) (Williams et al., 1994) displayed significantly higher correlations between RPE and minute ventilation, heart rate and oxygen uptake, compared to the Borg CR-10 scale (Borg & Borg, 2001), in children (10.4 ± 0.5 years) completing incremental treadmill running (Marinov, Mandadjieva & Kostianev, 2008). A significant difference in intraclass correlation was also observed between the pictorial-CERT scale (0.77) and the CR-10 scale (0.54) (Marinov et al., 2008). The findings highlight the use of pictorial cues as an aid in RPE in children. Roemmich et al. (2006) argued that scales containing both verbal and pictorial descriptors appear to be a more appropriate method of RPE collection with children. This may be because the children focus more on the pictorial descriptors rather than the verbal cues, which they may not fully understand (Parfitt, Shepherd & Eston, 2007). In the current thesis, the addition of the OMNI walking/running scale to assist in the delivery of CR-100 dRPE may have benefitted the players. In the current thesis, the OMNI walking/running scale was modified so that the verbal descriptors on the scale, reflected the verbal descriptors on the CR-100 RPE tablet application. The rationale was to marry up the verbal descriptors from the CR-100 scale to a pictorial descriptor which was aimed to aid the decision making of the child. The effectiveness of the OMNI walking/running scale as an aid in the current thesis remains unclear, however when observing the PCA, on only five occasions out of twenty-four (21%) did the CR-10 and CR-100 (dRPE-Overall) fall directly into the same principal component. On numerous occasions, twelve out of twenty-four (50%), they were partially explained within the same principal component. There is a suggestion that the presence of the OMNI walking/running scale impacted the RPE from the CR-100 scale as previously the two scales have shown high levels of agreeability. Numerous authors (Lamb 1995; Lamb, 1996; Lamb & Eston, 1997) have suggested the importance of utilising a scale adapted and validated for use with children. The use of the OMNI scale has been shown within children (Marinov, Mandadjieva & Kostianev, 2008) and more specifically within youth soccer (Rodríguez-Marroyo & Antoñan, 2015). The use of a child validated scale in the current thesis, albeit as merely a support mechanism, may explain the differences show in RPE CR-10 and CR-100.

5.4 The effect of pitch size and maturity status on heart rate responses

The HR responses for both pre- and post-PHV players fluctuated across pitch sizes and did not increase linearly with pitch size. Kelly and Drust (2009) suggested that pitch dimensions are not the primary factor in HR responses, as they reported a decrease in HR responses (91%, 90%, 89%) as pitch size increased (30 x 20m, 40 x 30m, 50 x 40m, respectively). It has been reported that HR responses may be influenced by more than just one's physical effort (Dellal et al., 2012; Silva, Cerqueira, Moreira & Marins, 2013). Towlson et al. (2020b) reported no meaningful difference in HR responses when players were bio-banded, which supports the findings of the current thesis as there were no significant differences in HR responses in the maturity matched bio-banded SSGs. There is evidence to suggest that one's HR is not directly influenced by their maturity status, as in the current thesis, on only one occasion there was a significant difference in HR between pre- and post-PHV players, this occurred on the large pitch condition (ES = 0.57, *p = 0.045*, *small*). Despite this, on two occasions both pre- and post-PHV players reported identical mean HRs on the medium (155 ± 30 beats.min^{-1}) and expansive pitch conditions (154 ± 27 (Post-PHV), ± 32 (Pre-PHV) beats.min^{-1}), in the Post-PHV vs Pre-PHV SSGs. Maturity status appears to play little impact upon heart responses in SSGs, however, differences in HR may be attributed to other factors, such as pitch dimensions.

SSGs (3 vs. 3) have shown to stimulate greater HR responses than large-sided games (LSGs) (9 vs. 9) (Owen, Wong, McKenna & Dellal, 2011). Equally, Dellal et al. (2012) found higher HR values in SSGs (4 vs. 4) compared to actual 11 vs. 11 match play. Casamichana & Castellano (2010) reported a significant difference between the small pitch size and the medium and large pitch sizes for %HR max and %mean HR in 5 vs. 5 SSGs. Larger pitch sizes have been associated with greater physiological load, irrespective of game-format or age of the players (Little & Williams, 2007; Rampinini et al., 2007; Köklü, Albayrak, Keysan, Alemdaroğlu & Dellal, 2013; Hodgson et al., 2014). The current thesis opposes that suggestion as the post-PHV players recorded their greatest mean HR on the large pitch condition (166 ± 33 beats.min^{-1}) and their lowest on the small pitch condition (156 ± 22 beats.min^{-1}), similarly the pre-PHV players recorded their lowest mean HR on the small pitch condition (150 ± 29 beats.min^{-1}), with their greatest on the medium pitch condition (157 ± 29 beats.min^{-1}), regardless of SSGs. Post-PHV vs Pre-PHV on the large pitch condition was the only incidence of a significant difference between pre-PHV (152 ± 26 beats.min^{-1}) and post-PHV (165 ± 22 beats.min^{-1}) players (mean difference 13 beats.min^{-}1, ES = 0.57, *p = 0.045, small*). In support of the current thesis Owen et al., (2004) found that in 4 vs. 4 SSGs across increasing pitch sizes (20x25m; 25x30m; 30x35m), the highest mean peak HR was witnessed on the 'medium' pitch size (25x30m). There is reason to suggest that HR does not increase linearly with pitch dimensions. This is supported further by Kelly and Drust (2009) who discovered there was no significant difference between mean HR and three increasing pitch sizes (30m x 20m; 40m x 30m; 50m x 40m) in 5 vs. 5 SSGs. Casamichana, Bradley and Castellano (2018) reported minimal differences in %HR Max across four different pitch sizes (40m x 25m; 66m x 25m; 40m x 50m; 66m x 50m). The current thesis did not statistically compare across pitch dimensions as in Kelly and Drust (2009) and Casamichana et al. (2018), however the fact pre- and post-PHV players mean HR did not increase incrementally with the pitch dimensions supports their findings. The results of the current thesis imply that increasing pitch dimensions will not increase the HR response of youth soccer players in SSGs. Bondarev (2011) cited the number of players as a potential reason for differences in HR. In a sample of junior rugby league players (mean age 14.5 ± 1.5 years), a nonsignificant effect was found between playing area size and %HR max in 4 vs. 4 and 6 vs. 6 SSGs (Foster, Twist, Lamb & Nicholas, 2010). However, Foster et al. (2010) did report a difference in %HR max between the 4 vs. 4 (90.6% HR max) and the 6 vs. 6 (86.2% HR max). Therefore, it can be assumed that pitch size does not significantly influence one's mean HR in 4 vs. 4 SSGs, in order to elicit different HR responses in SSGs it may be more appropriate to alter player numbers in SSGs as oppose to pitch dimensions.

5.5 The effect of pitch size on facets of physical and technical characteristics during bio-banded match-play

The thesis aimed to consider how relative pitch sizes affected the physiological and technical output of youth soccer players during SSG match-play. Post-PHV players mean total distance covered increased from the small to the large pitch size (436 ± 48m to 560 ± 56m), however they covered a lower mean total distance on the expansive pitch size (529 ± 106m) than they did on the large pitch size (560 ± 56m). This was not the case with the pre-PHV players, who's mean total distance covered increased from the small to the expansive pitch size (409 ± 45m to 538 ± 47m). It has been reported previously that increasing the surface area of the pitch size increases the physiological output (Aroso, Rebelo & Gomes-Pereira, 2004; Owen et al., 2004; Rampinini et al., 2007; Williams and Owen, 2007; Casamichana & Castellano, 2010; Hodgson et al., 2014; Olthof, Frencken & Lemmink, 2018). However, this is still up for debate as the opposite has been suggested by Kelly and Drust (2009). Casamichana et al. (2018) proposed that modifying the length of the pitch placed a greater physiological load on players than increasing the width of the pitch. It appears the distance between the goals had a greater impact on physiological output than the distance between the side lines

(Casamichana et al., 2018). A similar idea has been witnessed in competitive soccer match play (Castellano, Alvarez & Blanco-Villasenor, 2013), futsal (Vilar et al., 2012) and basketball (Leite et al., 2014). Players adapt their movement according to the location of the target (Gonçalves et al., 2017). In SSGs goal scoring opportunities are common (Casamichana & Castellano, 2010), which meant that players naturally gravitate to the central areas of the pitch, neglecting the space out wide (Casamichana et al., 2018). In the current thesis the effect of proximity to the goal is unclear, despite the aforementioned suggestions. The pitch dimensions in the current thesis increased equally in both width and length.

The mean total distance covered by both the pre- and post-PHV players increased as the pitch size increased with post-PHV players covering a greater total mean distance than pre-PHV players, with the exception of the expansive pitch condition (Post-PHV – 529 ± 106m, Pre-PHV – 538 ± 47m). It has been reported that within soccer match play, total distance covered is not affected by maturity status (Buchheit & Mendez-Villanueva, 2014; Towlson et al., 2020b). This may be due to the duration and dimensions of the pitch, as the space afforded to the players may have restricted any physical (dis)advantages associated to each maturity group (Towlson et al., 2020b). In the current thesis, only on the large pitch condition was a significant difference in mean total distance covered witnessed as post-PHV players covered a significantly greater mean total distance than the pre-PHV players (mean difference 38m, ES = 0.78, *p = 0.006, moderate*) . Conversely, Lovell et al. (2019) found as aPHV increased, so did the total distance covered per minute, albeit only marginally. It has been reported that in later maturing boys, categorised using skeletal age (TW2; Tanner et al., 1975), the mass moment on inertia during the swing-phase of the running mechanism is lower than in earlier maturing boys (Segers, De Clercq, Philippaerts &

Janssens, 2002). This potentially details an energy saving mechanism, as this would allow the front foot to be placed further in front of the body, therefore requiring less energy to move the foot forward in the next step (Segers et al., 2002). This may partially explain why pre-PHV players covered a greater mean distance than post-PHV players on the expansive pitch condition in the current thesis. This is not something that was possible to analyse within the current thesis. However, this may be something that future bio-banding research may wish to research further as it may lead to new ways in which practitioners can understand the maturational process.

In the current thesis it was found that post-PHV players covered less mean distance on the expansive pitch size (529 ± 106m) compared to pre-PHV players (538 ± 47m). Post-PHV players also covered a lower mean total distance on the expansive pitch size (529 ± 106m), than the large pitch size (560 ± 56m). This conflicts previously reported research that suggests increasing the surface area of the pitch size increases the physiological output (Aroso, Rebelo & Gomes-Pereira, 2004; Owen et al., 2004; Rampinini et al., 2007; Williams and Owen, 2007; Casamichana & Castellano, 2010). Pre-PHV players covered a greater mean distance (532 ± 45m) than post-PHV players (521 ± 125m) in the Post-PHV vs Pre-PHV SSGs on the expansive pitch condition, despite sharing a very similar mean number of releases (Post-PHV 8 ± 3; Pre-PHV 7 ± 4). The lower distance covered by the post-PHV players, compared to pre-PHV players, on the expansive pitch condition may be attributed to kicking distance. Post-PHV players may have an ability to kick the ball further, which allows them to do less running. Gersden (2008) reported that player stature explained 20% ($p < 0.000$) of the variability in kicking distance, with taller players able to strike the ball further. Age and stage of maturity significantly contributed to the variance (21%) of 'dribbling with a pass' ability in U13-U15 youth soccer players (Malina et al., 2005). Greater body-mass has also been positively associated with faster ball shooting speed ($p < 0.001$), in elite U14's (Wong, Chamari, Dellal & Wisloff, 2009). The current thesis chose not to measure kicking distance or dribbling as perception of effort (dRPE) between pre- and post-PHV players was the main focus of the research. The technical actions of the players were secondary to offer substance to the dRPE-T. It was felt that kicking distance and other technical actions may get lost or be of less relevance. There is a tentative suggestion, however, that a relationship may occur between anthropometric measures and performance benefits during the adolescent period of development (Unnithan et al., 2012). It appears that the apparent kicking advantage afforded to those advanced in maturation, coupled with a larger pitch dimension may have impacted running performance, in terms of mean total distance covered, as the post-PHV players were not required to run as great a distance as pre-PHV players due to their ability to kick the ball further.

A further explanation for the findings could be explained through the coaching philosophy employed within the respective clubs involved and the chronological age group coaches employed. Across an 8-year study observing professional soccer teams in the top three divisions of English soccer (Premier League, EFL Championship, EFL League One), Barrett et al. (2020) discovered substantial variation in training drills between nine elite head coaches. The findings were attributed to differing training philosophies between the head coaches of different clubs (Barrett et al., 2020). The findings are applicable within the current thesis sample as chronological age group coaches often change year-on-year, as the players move up the chronological age groups, they are often coached by a new coach. In the current thesis, the coaches were instructed not to give feedback or instruction during the SSGs, however on a number of occasions the coaches had to be reminded of this. Even without consistent side-line instruction from the coaches, due to the environment, the players were coached 3-4 times per week by the coach who may hold different expectations to another coach. The different coaches employed at each club, within each chronological age group squad, may impact upon the way each player is coached and in turn performs. A change in personnel may influence a player's physical output during training and match-play, depending on playing position and the coach's instructions (Barrett et al. 2020). Due to the nature of youth academy soccer, some coaches may be part-time members of staff and others full-time employees with varying degrees of qualifications (UEFA B – UEFA A) and experience which may impact upon the way in which they coach their players. The EPPP (Premier League, 2011) regulates academy soccer coaching in England, however, this does not stop each coach having their own interpretations on how they wish to instruct their players to play, or what they believe their players are capable of.

In the maturity matched bio-banded SSGs it was found that post-PHV players reported their greatest mean RPE (CR-10) on the medium pitch condition (4.70 ± 0.85 AU) and their lowest on the expansive pitch condition (4.19 ± 1.17 AU). Likewise, pre-PHV players reported their greatest mean RPE on the medium pitch condition (5.22 ± 0.95 AU), however, their lowest was recorded on the small pitch condition (4.53 ± 0.88 AU). The findings suggest that RPE does not increase linearly with pitch dimensions. The work of Casamichana and Castellano (2010) contradicts the findings of the current thesis as they reported a significant difference in RPE scores (CR-10) between the small pitch size (5.7 ± 1.0 AU) and the medium & large pitch sizes (6.7 ± 0.8 AU). Three differing pitch sizes were utilised in the study, small (32 x 23m – 73.6m^2), medium (50 x 35m – 175m^2), and large (62 x 44m – 272.8m^2) using 5 vs. 5, plus a goalkeeper, match play (Casamichana & Castellano, 2010). Barrett et al. (2018) reported a significantly greater dRPE-T when competing against top ranked teams, compared to middle and bottom ranked with elite top division soccer players. It may be accepted that when playing against a perceived greater challenge (e.g., a goalkeeper or higher ranked team) it elicits a greater RPE. This is further supported by Hill-Haas et al. (2010) who observed the physiological and psychological effects of overloaded/underloaded (3 vs. 4) SSGs. It was found that teams underloaded reported a significantly greater RPE than those overloaded, despite no significant difference in high intensity running, %HRmax or blood lactate (La^-) (Hill-Haas et al., 2010). The findings suggest that during a perceived greater challenge (i.e., pre-PHV competing against post-PHV, or underload vs. overload) there may be a psychological process that occurs in which there is a greater perception of effort.

6.0 Limitations

This thesis is the first of its kind to assess the usefulness of dRPE in maturity matched and mis-matched bio-banded SSGs, within a youth population, and therefore offers several limitations. Most notably being the methods used to obtain RPE (CR-10) and dRPE (CR-100). The CR-10 and CR-100 scales have previously displayed high levels of validity and reliability, with internal load measures, across different sports (Borg & Borg, 2002; Impellizzeri et al., 2004; Wallace, Slattery & Coutts, 2009). The scales have also been used to collect dRPE, within both the adult and youth population. However, the reliability and validity of dRPE in the youth population is still unknown. The current findings suggest the usefulness of dRPE should be viewed with caution due to the fact the dRPE method has not been validated with the youth population. Despite our best efforts to account for the dRPE method not being validated for use with youth athletes. The inconsistencies in the results, between the CR-10 and CR-100, which have previously been described as interchangeable (Fanchini et al., 2016) further extenuate this point. The present thesis accompanied the collection of dRPE (CR-100) with a modified OMNI walking/running scale, a scale previously validated for use with the youth population (Utter et al., 2002). However, there appeared to be little to no interaction with the accompanying OMNI walking/running scale whilst the players completed their dRPE. The OMNI walking/running scale was employed as a visual aid due to its validation with the youth population, however the level of interaction with the population appeared relatively low.

Another limitation was the sample size of just forty-three highly trained youth soccer players, despite this being greater than that witnessed in other bio-banded match-play studies (Abbott et al., 2019). Inferences regarding the effectiveness of bio-banding, to manipulate a physical output, must be taken with caution. It is suggested that future bio-banding research aims to address the flaws of smaller sample sizes and perhaps aims for a league-wide collaborative study to allow for robust statistical conclusions to be drawn. Despite this, the current thesis believes that some of the current findings display an interesting insight into how maturity status can affect dRPE scores, in particular the significant difference in dRPE-T scores between pre- and post-PHV players when competing against one another.

Another limitation may be the choice of maturity equation utilised within the thesis. The current thesis used the Khamis-Roche method (Khamis & Roche, 1994) to obtain %EASA. The method requires mid-parental height, which in the current thesis was obtained from self-reported parental statures. Self-reported parental height is adjusted for the overestimation of height which reduces the accuracy compared to study measured parental height. Another issue with gathering parental height is that players may come from a single parent background so that the height of one parent may not be possible to obtain which leads to further inaccuracies. The Khamis-Roche method (Khamis & Roche, 1994) was validated against the Fels longitudinal study (Malina et al., 2007b) which utilised a sample of middle-class Caucasian American children, this is problematic due to the increasingly diverse environment of an academy soccer team and may question the accuracy and usefulness of the method in correctly identifying one's %EASA (Merkel, 2014). This is relevant in the current thesis as the sample included players of various ethnic backgrounds and the accuracy of the %EASA may be low for those not from the validated sample's background. It has long since been argued that all methods require further validation within athletic populations of different ethnic backgrounds (Marshall & Tanner, 1970). It needs to be considered, the measurement of growth and maturation in children is a non-linear process (Towlson et al., 2020a).

Another limitation was the lack of a 'control' method. The thesis utilised a 'mixed maturity' condition with the aim of replicating that witnessed in conventional chronological age groupings. The mixed maturity groupings were in fact comprised of players from different chronological age groupings. This is likely to have increased the variance in maturity-associated anthropometric and physical characteristics. This is a limitation as it may have increased the efficacy of the maturity matched and mis-matched bio-banded SSGs. The lack of a true control was decided upon due to the disruption it would it cause to regular training and athletic development programmes.

A further limitation is that the pitch dimensions may not be suitable to produce accurate soccer match-play data. The pitch dimensions did not match that of a typical soccer pitch in that both sides of the area were the same length, whereas official soccer pitches are greater in length than what they are width. As it has been suggested that proximity to the goal is important in SSGs (Casamichana et al., 2018), it may be difficult to replicate the results on a rectangular pitch, as the dimensions of the pitch may elicit a different physical response. Within soccer academies one's technical ability is constantly scrutinised for talent identification purposes as well as team selections and positional allocations. The irregular pitch dimensions may diminish the effectiveness of maturity matched and mis-matched bio-banded SSGs as a means of talent identification.

A final limitation identified within the thesis is the use of the term 'release' as a technical key performance indicator. Playermaker^{TM} describe the term 'release' as any action in which the player strikes the ball, and without video footage to analyse each player it is unclear the accuracy or type of release that has been counted. During opposed soccer drills, it was found that the Playermaker^{TM} IMU correctly recalled 88% of all releases, with 92.6% of all classified releases being releases (Gad et al., 2020).

The term ‘release’, however, may not have been the most appropriate as a key performance indicator in which to ascertain how a technical action may impact one’s cognitive load (dRPE-T).

7.0 Conclusion

In conclusion, the findings of the thesis suggest that there is little usefulness in the collection of dRPE within the youth population in soccer small-sided games. This is concluded primarily through the PCA as on twelve occasions out of twenty-four (50%) the four facets of dRPE (dRPE-Overall, dRPE-B, dRPE-L & dRPE-T) were all explained by the same principal component (PC1). On twenty-one occasions out of twenty-four (87.5%) the four facets of dRPE were explained by the same principal component (PC1), however the variability of certain facets of dRPE were also partially explained by another principal component. When observing the data further, it must be noted there was a significant difference in dRPE-T scores between pre- and post-PHV maturing players in maturity mis-matched SSGs across all pitch conditions. These early findings suggest that maturational differences may run far deeper than simply a physical advantage afforded to those advanced in maturation. Further research may be required to fully understand the effect of maturity status upon youth soccer player's cognitive load. The thesis also leans on the side of support for the use of maturity matched bio-banding as an effective training method in youth soccer players. Post-PHV players covered greater total mean distance in maturity matched bio-banded SSGs and perceived competition as a greater challenge, as witnessed in the respective dRPE scores. Pre-PHV players also perceived maturity matched bio-banded SSGs as less of a challenge physically, as witnessed in their respective dRPE. Maturity matched bio-banded SSGs offer a previously unseen physical challenge to post-PHV players, whilst simultaneously offering a greater opportunity for the expression of technical and physical skills for pre-PHV players. However, caution must be aired, as despite the sample size (n = 43) being greater than that of previously published work (Abbott et al., 2019), the levels of measurement uncertainty across both physical and technical outputs must be considered. The research echo's that of previous work (Towlson et al., 2020b) in that such lines of investigation require the support of national and domestic professional league governing bodies. The support of national governing bodies allows for greater funding and a multi-club and academic institution involvement which will further enhance the sample sizes and in turn, the research's ability to generalise the findings for the wider population of academy youth soccer. The knowledge and conclusions drawn can further benefit the quality of talent identification and youth soccer for the future.

7.1 Future Research Recommendations

Future research should aim to further understand the usefulness of dRPE within youth soccer SSGs, in particular dRPE-T as a measure of cognitive load in youth soccer players. The findings of the current thesis displayed a significant difference in dRPE-T between pre- and post-PHV players across all pitch sizes. dRPE-T was the only facet of dRPE to display a significant difference between pre- and post-PHV players consistently across all pitch sizes. It has been reported that post-PHV players may possess a greater technical/tactical knowledge due to their increased age and experience (Williams, 2000; Ward & Williams, 2003). There is limited research into bio-banded soccer training and match-play (Abbott et al., 2019; Romann et al., 2020; Towlson et al., 2020b), and the physical differences between pre- and post-PHV players (Lovell et al., 2015; Pena-Gonzalez et al., 2019; Towlson et al., 2020b). However, the technical/tactical/cognitive effect of pre – and post-PHV has not been previously researched, and the findings of the current thesis suggest this may be greater than the physical differences associated with differing maturation. The findings of the current thesis, in that, pre-PHV players constantly rated a greater dRPE-T than post-PHV in maturity mis-matched bio-banded SSGs suggests that the post-PHV may possess a technical/tactical/cognitive advantage over those delayed in maturation. It may be crucial to understand the effect this advantage plays in the talent identification process.

A second recommendation from the current thesis is that further research is required into the use of dRPE with the youth population. This research is the first of its kind to utilise dRPE in youth soccer players SSGs. The findings of the current thesis suggest that dRPE may not be an appropriate method of collecting RPE in youth soccer SSGs as it fails to inform the practitioner of anything different than just one rating of RPE. Through the use of a PCA it was found that on twelve occasions out of twenty-four (50%) all four facets of dRPE were explained by the same principal component (PC1). It was further found that in twenty-one out of twenty-four occasions (87.5%) the four facets of dRPE were explained within the same principal component, however they were also partially explained within another principal component. The findings of the PCA, coupled with the fact there were no significant differences in dRPE-B, between pre- and post-PHV players, despite significant differences in mean total distance and mean HR suggest dRPE may not be appropriate in youth soccer players. Therefore, there is a need for further research into the usefulness of dRPE in youth soccer SSGs. Equally, MacPherson et al. (2019) reported no significant difference between dRPE-B, dRPE-L & dRPE-T between semi-professional soccer players. However, in the current thesis there was a significant difference in dRPE-T, between pre- and post-PHV players, across all pitch sizes which may suggest there is a need to further enhance our understanding as to why this may occur. The research of Weston et al., (2014); McLaren et al., (2016; 2017; 2018) and Barrett et al., (2018) support the use of dRPE across match-play and various training types. They did however use adult athletes, and the use of dRPE within the youth population remains under researched.

7.2 Practical applications

- It appears that no unique information can be collected through dRPE (dRPE-Overall, dRPE-B, dRPE-L & dRPE-T) within the youth population for SSGs, therefore practitioners are best suited to only gather one measure of training load.
- Maturity matched bio-banded SSGs allow for a greater physical challenge to those advanced in maturation, whilst simultaneously allowing those delayed in maturation a greater chance to display their technical/tactical and physical abilities which may be overlooked in chronological age competition.
- Pitch dimensions do not significantly affect HR, so coaches are best suited to alter player numbers, rather than pitch dimensions to elicit a HR response.

8.0 References

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9.0 Appendices

Table (3). Key performance indicators for both all fixture types on the small pitch condition (17m x 17m).

Pitch Size	SSG	Maturity Status	Total Distance (m)	Mean HR (beats.min^{-1})	RPE (CR-10)	RPE-Overall (CR-100)	RPE-B (CR-100)	RPE-L (CR-100)	RPE-T (CR-100)	Releases
Small	Post-PHV 1 vs Post-PHV 2	Post-PHV Post-PHV	442 ± 37 445 ± 77 ***ES = 0.05 (T)*** ***p = 0.933***	170 ± 10 147 ± 27 ***ES = 1.26 (L)*** ***p = 0.081***	4.83 ± 0.74 4.83 ± 0.74 ***ES = 0 (T)*** ***p = 1.000***	46.17 ± 12.50 49.60 ± 8.20 ***ES = 0.33 (S)*** ***p = 0.612***	47.00 ± 17.41 42.50 ± 13.14 ***ES = 0.29 (S)*** ***p = 0.624***	42.17 ± 7.94 35.33 ± 16.45 ***ES = 0.56 (S)*** ***p = 0.381***	38.00 ± 13.48 44.00 ± 25.04 ***ES = 0.31 (S)*** ***p = 0.617***	8 ± 3 11 ± 6 ***ES = 0.74 (M)*** ***p = 0.244***
	Post-PHV vs Pre-PHV	Post-PHV Pre-PHV	436 ± 42 415 ± 48 ***ES = 0.47 (S)*** ***p = 0.115***	158 ± 20 149 ± 31 ***ES = 0.34 (S)*** ***p = 0.299***	4.45 ± 1.40 4.59 ± 0.98 ***ES = 0.12 (T)*** ***p = 0.690***	41.05 ± 15.07 48.62 ± 11.91 ***ES = 0.56 (S)*** ***p = 0.056***	43.50 ± 14.40 39.48 ± 14.91 ***ES = 0.27 (S)*** ***p = 0.352***	36.15 ± 15.84 37.90 ± 13.44 ***ES = 0.12 (T)*** ***p = 0.680***	39.15 ± 17.47 51.21 ± 10.19* ***ES = 0.87 (M)*** ***p = 0.004***	9 ± 2 9 ± 4 ***ES = 0.03 (T)*** ***p = 0.931***
	Pre-PHV 1 vs Pre-PHV 2	Pre-PHV Pre-PHV	391 ± 22 416 ± 54 ***ES = 0.66 (M)*** ***p = 0.255***	156 ± 21 154 ± 32 ***ES = 0.06 (T)*** ***p = 0.921***	4.40 ± 0.76 4.33 ± 0.52 ***ES = 0.27 (S)*** ***p = 0.652***	41.13 ± 21.61 47.00 ± 14.95 ***ES = 0.32 (S)*** ***p = 0.580***	34.50 ± 12.93 41.17 ± 21.01 ***ES = 0.39 (S)*** ***p = 0.476***	34.75 ± 23.01 50.00 ± 15.72 ***ES = 0.79 (M)*** ***p = 0.189***	49.13 ± 19.92 50.33 ± 15.29 ***ES = 0.07 (T)*** ***p = 0.904***	7 ± 3 6 ± 3 ***ES = 0.11 (T)*** ***p = 0.837***
	Mixed 1/ Mixed 2 vs Mixed 3/ Mixed 4 (Mixed 1)	Post-PHV Pre-PHV	416 ± 33 391 ± 51 ***ES = 0.60 (S)*** ***p = 0.060***	144 ± 26 130 ± 60 ***ES = 0.31 (S)*** ***p = 0.351***	5.05 ± 0.83 4.89 ± 0.64 ***ES = 0.22 (S)*** ***p = 0.455***	46.95 ± 10.31 44.96 ± 10.59 ***ES = 0.19 (T)*** ***p = 0.523***	45.95 ± 11.50 41.00 ± 14.99 ***ES = 0.37 (S)*** ***p = 0.224***	41.35 ± 12.73 40.30 ± 15.22 ***ES = 0.08 (T)*** ***p = 0.803***	44.00 ± 13.06 49.63 ± 9.69 ***ES = 0.49 (S)*** ***p = 0.096***	8. ± 3 8 ± 3 ***ES = 0.07 (T)*** ***p = 0.806***
	Mixed 1 vs Mixed 2 (Mixed 2)	Post-PHV Pre-PHV	438 ± 55 411 ± 41 ***ES = 0.57 (S)*** ***p = 0.275***	155 ± 24 115 ± 56 ***ES = 1.01 (M)*** ***p = 0.082***	4.50 ± 1.31 4.88 ± 0.84 ***ES = 0.35 (S)*** ***p = 0.506***	48.75 ± 13.08 47.88 ± 10.56 ***ES = 0.07 (T)*** ***p = 0.885***	53.38 ± 13.31 47.50 ± 16.05 ***ES = 0.40 (S)*** ***p = 0.439***	43.25 ± 23.83 40.13 ± 10.74 ***ES = 0.18 (T)*** ***p = 0.740***	42.37 ± 17.44 52.25 ± 6.71 ***ES = 0.82 (M)*** ***p = 0.157***	7 ± 3 8 ± 5 ***ES = 0.27 (S)*** ***p = 0.446***
	Mixed 3 vs Mixed 4 (Mixed 3)	Post-PHV Pre-PHV	427 ± 17 360 ± 55* ***ES = 1.86 (L)*** ***p = 0.027***	126 ± 74 161 ± 31 ***ES = 0.66 (M)*** ***p = 0.287***	4.60 ± 0.89 4.57 ± 1.27 ***ES = 0.03 (T)*** ***p = 0.967***	53.40 ± 16.23 53.43 ± 5.06 ***ES = 0 (T)*** ***p = 0.997***	50.00 ± 16.33 44.29 ± 13.87 ***ES = 0.38 (S)*** ***p = 0.527***	43.60 ± 19.01 38.86 ± 18.71 ***ES = 0.25 (S)*** ***p = 0.676***	50.60 ± 18.24 51.29 ± 9.79 ***ES = 0.05 (T)*** ***p = 0.934***	8 ± 3 8 ± 3 ***ES = 0.03 (T)*** ***p = 0.960***

All key performance indicators displayed across all SSGs (Banded and Mixed) on the Small (17m x 17m) pitch size. Effect size shown in bold (**T**- Trivial, **S** – Small, **M** – Moderate, **L** – Large, **VL** - Very Large). * shows significance at the 0.05 level.

Table (4). Key performance indicators for both all fixture types on the medium pitch condition (24m x 24m).

Pitch Size	SSG	Maturity Status	Total Distance (m)	Mean HR (beats.min^{-1})	RPE (CR-10)	RPE-Overall (CR-100)	RPE-B (CR-100)	RPE-L (CR-100)	RPE-T (CR-100)	Releases
Medium	Post-PHV 1 vs Post-PHV 2	Post-PHV Post-PHV	506 ± 44 529 ± 46 ***ES = 0.52 (S)*** ***p = 0.398***	161 ± 25 143 ± 29 ***ES = 0.66 (M)*** ***p = 0.314***	4.14 ± 0.69 4.50 ± 0.55 ***ES = 0.58 (S)*** ***p = 0.330***	36.14 ± 7.78 50.17 ± 7.65* ***ES = 1.82 (L)*** ***p = 0.008***	44.14 ± 7.90 53.00 ± 10.94 ***ES = 0.94 (M)*** ***p = 0.119***	39.29 ± 6.58 47.50 ± 15.11 ***ES = 0.76 (M)*** ***p = 0.217***	33.29 ± 11.81 49.83± 19.42 ***ES = 1.06 (M)*** ***p = 0.085***	9 ± 3 7 ± 2 ***ES = 0.78 (M)*** ***p = 0.222***
	Post-PHV vs Pre-PHV	Post-PHV Pre-PHV	493 ± 92 458 ± 42 ***ES = 0.52 (S)*** ***p = 0.102***	155 ± 30 155 ± 30 ***ES = 0 (T)*** ***p = 0.993***	4.95 ± 0.89 5.32 ± 0.83 ***ES = 0.43 (S)*** ***p = 0.163***	41.35 ± 10.92 53.44 ± 10.65* ***ES = 1.12 (M)*** ***p = 0.001***	42.45 ± 14.73 47.56 ± 13.97 ***ES = 0.36 (S)*** ***p = 0.241***	37.90 ± 9.75 43.64 ± 14.55 ***ES = 0.47 (S)*** ***p = 0.138***	40.95 ± 15.11 50.72 ± 13.76* ***ES = 0.68 (M)*** ***p = 0.029***	8 ± 2 8 ± 4 ***ES = 0.29 (S)*** ***p = 0.356***
	Pre-PHV 1 vs Pre-PHV 2	Pre-PHV Pre-PHV	479 ± 30 492 ± 43 ***ES = 0.37 (S)*** ***p = 0.566***	170 ± 10 152 ± 29 ***ES = 0.89 (M)*** ***p = 0.229***	5.20 ± 1.30 4.86 ± 1.07 ***ES = 0.29 (S)*** ***p = 0.627***	49.75 ± 11.96 48.43 ± 6.16 ***ES = 0.15 (T)*** ***p = 0.811***	49.60 ± 12.58 44.14 ± 6.82 ***ES = 0.56 (S)*** ***p = 0.352***	49.20 ± 10.62 42.43 ± 7.16 ***ES = 0.76 (M)*** ***p = 0.214***	43.60 ± 10.34 42.57 ± 10.81 ***ES = 0.10 (T)*** ***p = 0.872***	5 ± 3 10 ± 3* ***ES = 1.44 (L)*** ***p = 0.031***
	Mixed 1/ Mixed 2 vs Mixed 3/ Mixed 4 (Mixed 1)	Post-PHV Pre-PHV	472 ± 167 444 ± 65 ***ES = 0.24 (S)*** ***p = 0.477***	133 ± 60 143 ± 46 ***ES = 0.19 (T)*** ***p = 0.533***	4.90 ± 1.02 5.41 ± 1.05 ***ES = 0.49 (S)*** ***p = 0.120***	46.95 ± 12.18 50.86 ± 12.94 ***ES = 0.31 (S)*** ***p = 0.320***	48.75 ± 12.29 48.41 ± 14.28 ***ES = 0.03 (T)*** ***p = 0.935***	45.80 ± 16.71 46.59 ± 11.31 ***ES = 0.06 (T)*** ***p = 0.857***	46.45 ± 17.33 50.32 ± 12.45 ***ES = 0.26 (S)*** ***p = 0.408***	9 ± 3 8 ± 3 ***ES = 0.36 (S)*** ***p = 0.251***
	Mixed 1 vs Mixed 2 (Mixed 2)	Post-PHV Pre-PHV	511 ± 44 462 ± 70 ***ES = 0.88 (M)*** ***p = 0.128***	137 ± 63 143 ± 37 ***ES = 0.13 (T)*** ***p = 0.812***	4.00 ± 0.82 5.13± 0.99* ***ES = 1.25 (L)*** ***p = 0.034***	37.00 ± 10.47 46.25 ± 17.77 ***ES = 0.66 (M)*** ***p = 0.250***	41.43 ± 17.16 45.75 ± 16.53 ***ES = 0.26 (S)*** ***p = 0.628***	35.57 ± 17.35 41.75 ± 14.41 ***ES = 0.39 (S)*** ***p = 0.464***	39.14 ± 13.89 43.63 ± 16.63 ***ES = 0.29 (S)*** ***p = 0.584***	9 ± 4 8 ± 2 ***ES = 0.50 (S)*** ***p = 0.402***
	Mixed 3 vs Mixed 4 (Mixed 3)	Post-PHV Pre-PHV	427 ± 214 458 ± 52 ***ES = 0.24 (S)*** ***p = 0.735***	122 ± 64 167 ± 16 ***ES = 1.12 (M)*** ***p = 0.129***	5.33 ± 0.52 5.83 ± 0.98 ***ES = 0.67 (M)*** ***p = 0.296***	46.50 ± 8.87 57.83 ± 9.99 ***ES = 1.20 (L)*** ***p = 0.064***	57.00 ± 15.79 54.33 ± 13.49 ***ES = 0.18 (T)*** ***p = 0.760***	49.17 ± 13.08 53.33 ± 15.73 ***ES = 0.29 (S)*** ***p = 0.629***	58.67 ± 11.06 55.50 ± 13.75 ***ES = 0.26 (S)*** ***p = 0.670***	9 ± 2 10 ± 4 ***ES = 0.26 (S)*** ***p = 0.677***

All key performance indicators displayed across all SSGs (Banded and Mixed) on the Medium (24m x 24m) pitch size. Effect size shown in bold (**T**- Trivial, **S** – Small, **M** – Moderate, **L** – Large, **VL** - Very Large). * shows significance at the 0.05 level.

Table (5). Key performance indicators for both all fixture types on the large pitch condition (29.5m x 29.5m).

Pitch Size	SSG	Maturity Status	Total Distance (m)	Mean HR (beats.min^{-1})	RPE (CR-10)	RPE-Overall (CR-100)	RPE-B (CR-100)	RPE-L (CR-100)	RPE-T (CR-100)	Releases
	Post-PHV 1 vs Post-PHV 2	Post-PHV Post-PHV	573 ± 58 575 ± 57 ***ES = 0.04 (T)*** ***p = 0.942***	164 ± 22 175 ± 12 ***ES = 0.65 (M)*** ***p = 0.247***	4.57 ± 0.79 5.50 ± 0.76* ***ES = 0.12 (T)*** ***p = 0.037***	39.50 ± 7.77 49.00 ± 10.68 ***ES = 1.03 (M)*** ***p = 0.099***	46.29 ± 7.48 53.71 ± 14.73 ***ES = 0.67 (M)*** ***p = 0.257***	45.00 ± 13.36 42.57 ± 15.24 ***ES = 0.17 (T)*** ***p = 0.757***	41.71 ± 10.50 48.29± 16.57 ***ES = 0.49 (S)*** ***p = 0.393***	7 ± 3 7 ± 3 ***ES = 0.04 (T)*** ***p = 0.946***
	Post-PHV vs Pre-PHV	Post-PHV Pre-PHV	553 ± 56 515 ± 43* ***ES = 0.78 (M)*** ***p = 0.006***	165 ± 22 152 ± 26* ***ES = 0.57 (S)*** ***p = 0.045***	4.07 ± 0.98 4.96 ± 1.00* ***ES = 0.90 (M)*** ***p = 0.001***	39.43 ± 14.77 48.33 ± 12.91* ***ES = 0.64 (M)*** ***p = 0.021***	41.21 ± 16.18 42.64 ± 14.18 ***ES = 0.09 (T)*** ***p = 0.727***	33.14 ± 10.36 40.43 ± 17.53 ***ES = 0.52 (S)*** ***p = 0.064***	35.96 ± 12.69 48.75 ± 15.10* ***ES = 0.92 (M)*** ***p = 0.001***	8 ± 3 7 ± 4 ***ES = 0.47 (S)*** ***p = 0.79***
Large	Pre-PHV 1 vs Pre-PHV 2	Pre-PHV Pre-PHV	504 ± 37 544 ± 56 ***ES = 0.87 (M)*** ***p = 0.118***	169 ± 16 163 ± 21 ***ES = 0.33 (S)*** ***p = 0.559***	4.88 ± 0.99 4.00 ± 1.16 ***ES = 0.82 (M)*** ***p = 0.138***	51.25 ± 13.81 43.00 ± 11.28 ***ES = 0.66 (M)*** ***p = 0.232***	48.38 ± 21.68 36.29 ± 16.66 ***ES = 0.63 (M)*** ***p = 0.2524m***	41.13 ± 17.03 35.57 ± 16.87 ***ES = 0.33 (S)*** ***p = 0.538***	49.63 ± 14.95 45.43 ± 13.69 ***ES = 0.29 (S)*** ***p = 0.582***	8 ± 3 6 ± 4 ***ES = 0.58 (S)*** ***p = 0.294***
	Mixed 1/ Mixed 2 vs Mixed 3/ Mixed 4 (Mixed 1)	Post-PHV Pre-PHV	530 ± 47 488 ± 45.47* ***ES = 0.92 (M)*** ***p = 0.002***	153 ± 51 149 ± 4 ***ES = 0.09 (T)*** ***p = 0.763***	5.33 ± 0.70 5.00 ± 1.10 ***ES = 0.37 (S)*** ***p = 0.211***	51.00 ± 7.17 50.85 ± 14.74 ***ES = 0.01 (T)*** ***p = 0.963***	52.04 ± 9.68 48.08 ± 15.64 ***ES = 0.31 (S)*** ***p = 0.291***	45.25 ± 11.99 48.62 ± 17.11 ***ES = 0.23 (S)*** ***p = 0.428***	49.46 ± 12.78 51.00 ± 16.97 ***ES = 0.10 (T)*** ***p = 0.720***	7 ± 3 7 ± 3 ***ES = 0.11 (T)*** ***p = 0.697***
	Mixed 1 vs Mixed 2 (Mixed 2)	Post-PHV Pre-PHV	543 ± 57 518 ± 43 ***ES = 0.50 (S)*** ***p = 0.371***	168 ± 11 143 ± 64 ***ES = 0.65 (M)*** ***p = 0.343***	5.00 ± 0.58 5.00 ± 0.58 ***ES = 0 (T)*** ***p = 1.000***	43.71 ± 11.22 47.71 ± 8.52 ***ES = 0.41 (S)*** ***p = 0.467***	49.57 ± 13.56 47.86 ± 8.88 ***ES = 0.15 (T)*** ***p = 0.784***	48.71 ± 15.07 47.71 ± 10.31 ***ES = 0.08 (T)*** ***p = 0.887***	49.00 ± 9.26 49.57 ± 12.39 ***ES = 0.05 (T)*** ***p = 0.924***	7 ± 3 8 ± 3 ***ES = 0.20 (T)*** ***p = 0.714***
	Mixed 3 vs Mixed 4 (Mixed 3)	Post-PHV Pre-PHV	529 ± 36 475 ± 54 ***ES = 1.19 (M)*** ***p = 0.084***	173 ± 12 137 ± 63 ***ES = 0.97 (M)*** ***p = 0.238***	4.80 ± 1.10 4.86 ± 0.38 ***ES = 0.08 (T)*** ***p = 0.899***	52.60 ± 11.52 58.86 ± 16.79 ***ES = 0.44 (S)*** ***p = 0.490***	49.60 ± 8.79 48.14 ± 15.02 ***ES = 0.03 (T)*** ***p = 0.851***	51.00 ± 12.35 44.29 ± 12.57 ***ES = 0.54 (S)*** ***p = 0.380***	59.40 ± 13.26 54.00 ± 17.87 ***ES = 0.35 (S)*** ***p = 0.581***	6 ± 3 7.00 ± 4.00 ***ES = 0.17 (T)*** ***p = 0.786***

All key performance indicators displayed across all SSGs (Banded and Mixed) on the Large (29.5m x 29.5m) pitch size. Effect size shown in bold (**T**- Trivial, **S** – Small, **M** – Moderate, **L** – Large, **VL** - Very Large). * shows significance at the 0.05 level.

Table (6). Key performance indicators for both all fixture types on the expansive pitch condition (34m x 34m).

Pitch Size	SSG	Maturity Status	Total Distance (m)	Mean HR (beats.min^{-1})	RPE (CR-10)	RPE-Overall (CR-100)	RPE-B (CR-100)	RPE-L (CR-100)	RPE-T (CR-100)	Releases
Expansive	Post-PHV 1 vs Post-PHV 2	Post-PHV Post-PHV	559 ± 56 516 ± 38 ***ES = 0.92 (M)*** ***p = 0.196***	175 ± 9 156 ± 27 ***ES = 1.09 (M)*** ***p = 0.130***	4.50 ± 0.93 3.75 ± 0.96 ***ES = 0.79 (M)*** ***p = 0.220***	44.25 ± 12.88 42.50 ± 10.41 ***ES = 0.15 (T)*** ***p = 0.819***	43.75 ± 14.46 44.25 ± 9.03 ***ES = 0.04 (T)*** ***p = 0.951***	37.50 ± 11.12 38.00 ± 14.86 ***ES = 0.04 (T)*** ***p = 0.949***	40.75 ± 10.05 40.50 ± 18.43 ***ES = 0.02 (T)*** ***p = 0.976***	7 ± 3 8 ± 3 ***ES = 0.26 (S)*** ***p = 0.694***
	Post-PHV vs Pre-PHV	Post-PHV Pre-PHV	512 ± 134 542 ± 42 ***ES = 0.34 (S)*** ***p = 0.328***	154 ± 27 154 ± 32 ***ES = 0.01 (T)*** ***p = 0.970***	4.16 ± 1.28 5.10 ± 1.00* ***ES = 0.82 (M)*** ***p = 0.009***	40.88 ± 12.17 51.43 ± 8.86* ***ES = 1.00 (M)*** ***p = 0.002***	38.68 ± 14.62 44.95 ± 12.19 ***ES = 0.47 (S)*** ***p = 0.126***	33.64 ± 11.64 43.52 ± 12.44* ***ES = 0.82 (M)*** ***p = 0.008***	34.48 ± 10.79 48.05 ± 9.89* ***ES = 1.31 (L)*** ***p = 0.000***	8 ± 3 7 ± 4 ***ES = 0.20 (S)*** ***p = 0.494***
	Pre-PHV 1 vs Pre-PHV 2	Pre-PHV Pre-PHV	532 ± 68 577 ± 35 ***ES = 0.86 (M)*** ***p = 0.264***	164 ± 16 139 ± 49 ***ES = 0.79 (M)*** ***p = 0.359***	5.14 ± 0.69 4.50 ± 0.58 ***ES = 1.01 (M)*** ***p = 0.152***	47.86 ± 10.35 45.50 ± 7.51 ***ES = 0.26 (S)*** ***p = 0.701***	39.00 ± 6.06 50.00 ± 11.23 ***ES = 1.27 (L)*** ***p = 0.060***	42.43 ± 7.98 45.25 ± 12.34 ***ES = 0.28 (S)*** ***p = 0.652***	49.00 ± 10.33 48.75 ± 12.61 ***ES = 0.02 (T)*** ***p = 0.972***	7 ± 4 7 ± 2 ***ES = 0.05 (T)*** ***p = 0.949***
	Mixed 1/ Mixed 2 vs Mixed 3/ Mixed 4 (Mixed 1)	Post-PHV Pre-PHV	459 ± 220 486 ± 116 ***ES = 0.16 (T)*** ***p = 0.588***	143 ± 61 131 ± 59 ***ES = 0.19 (T)*** ***p = 0.514***	4.95 ± 0.79 5.14 ± 0.71 ***ES = 0.25 (S)*** ***p = 0.377***	47.91 ± 8.62 52.82 ± 8.20* ***ES = 0.58 (S)*** ***p = 0.045***	47.77 ± 10.73 45.71 ± 14.86 ***ES = 0.16 (T)*** ***p = 0.587***	48.73 ± 15.15 46.11 ± 14.91 ***ES = 0.17 (T)*** ***p = 0.543***	46.77 ± 10.60 52.00 ± 11.47 ***ES = 0.47 (S)*** ***p = 0.105***	6 ± 2 7 ± 3 ***ES = 0.28 (S)*** ***p = 0.353***
	Mixed 1 vs Mixed 2 (Mixed 2)	Post-PHV Pre-PHV	532 ± 66 464 ± 207 ***ES = 0.50 (S)*** ***p = 0.392***	142 ± 62 158 ± 22 ***ES = 0.40 (S)*** ***p = 0.515***	4.75 ± 0.89 4.86 ± 0.90 ***ES = 0.12 (T)*** ***p = 0.820***	43.00 ± 5.66 47.29 ± 11.04 ***ES = 0.51 (S)*** ***p = 0.352***	44.00 ± 8.67 48.43 ± 7.32 ***ES = 0.55 (S)*** ***p = 0.309***	41.75 ± 11.88 52.14 ± 8.09 ***ES = 1.04 (M)*** ***p = 0.073***	43.00 ± 12.46 51.29 ± 12.27 ***ES = 0.67 (M)*** ***p = 0.218***	7 ± 3 7 ± 3 ***ES = 0.18 (T)*** ***p = 0.731***
	Mixed 3 vs Mixed 4 (Mixed 3)	Post-PHV Pre-PHV	454 ± 242 494 ± 54 ***ES = 0.27 (S)*** ***p = 0.703***	136 ± 70 161 ± 21 ***ES = 0.54 (S)*** ***p = 0.429***	5.17 ± 0.41 5.67 ± 1.03 ***ES = 0.69 (M)*** ***p = 0.296***	49.50 ± 9.16 57.33 ± 8.89 ***ES = 0.87 (M)*** ***p = 0.164***	47.17 ± 8.82 49.33 ± 18.14 ***ES = 0.16 (T)*** ***p = 0.798***	48.00 ± 11.05 40.67 ± 16.27 ***ES = 0.54 (S)*** ***p = 0.382***	48.67 ± 9.93 55.00 ± 12.59 ***ES = 0.56 (S)*** ***p = 0.356***	9 ± 2 7 ± 3 ***ES = 0.67 (M)*** ***p = 0.288***

All key performance indicators displayed across all SSGs (Banded and Mixed) on the Expansive (34m x 34m) pitch size. Effect size shown in bold (**T**- Trivial, **S** – Small, **M** – Moderate, **L** – Large, **VL** - Very Large). * shows significance at the 0.05 level.

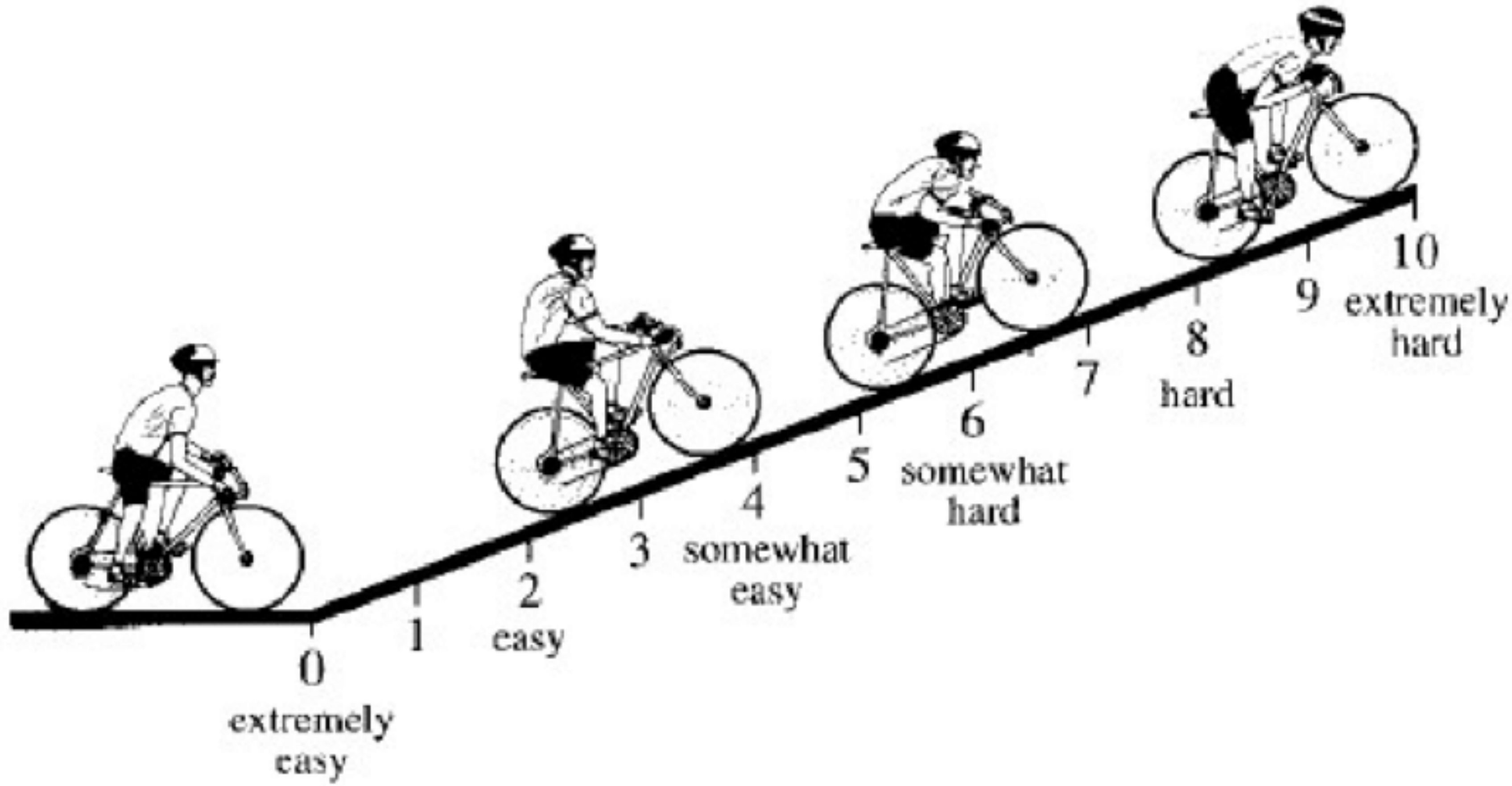

Figure 1 – OMNI cycling scale, developed by Robertson et al., 2000 .

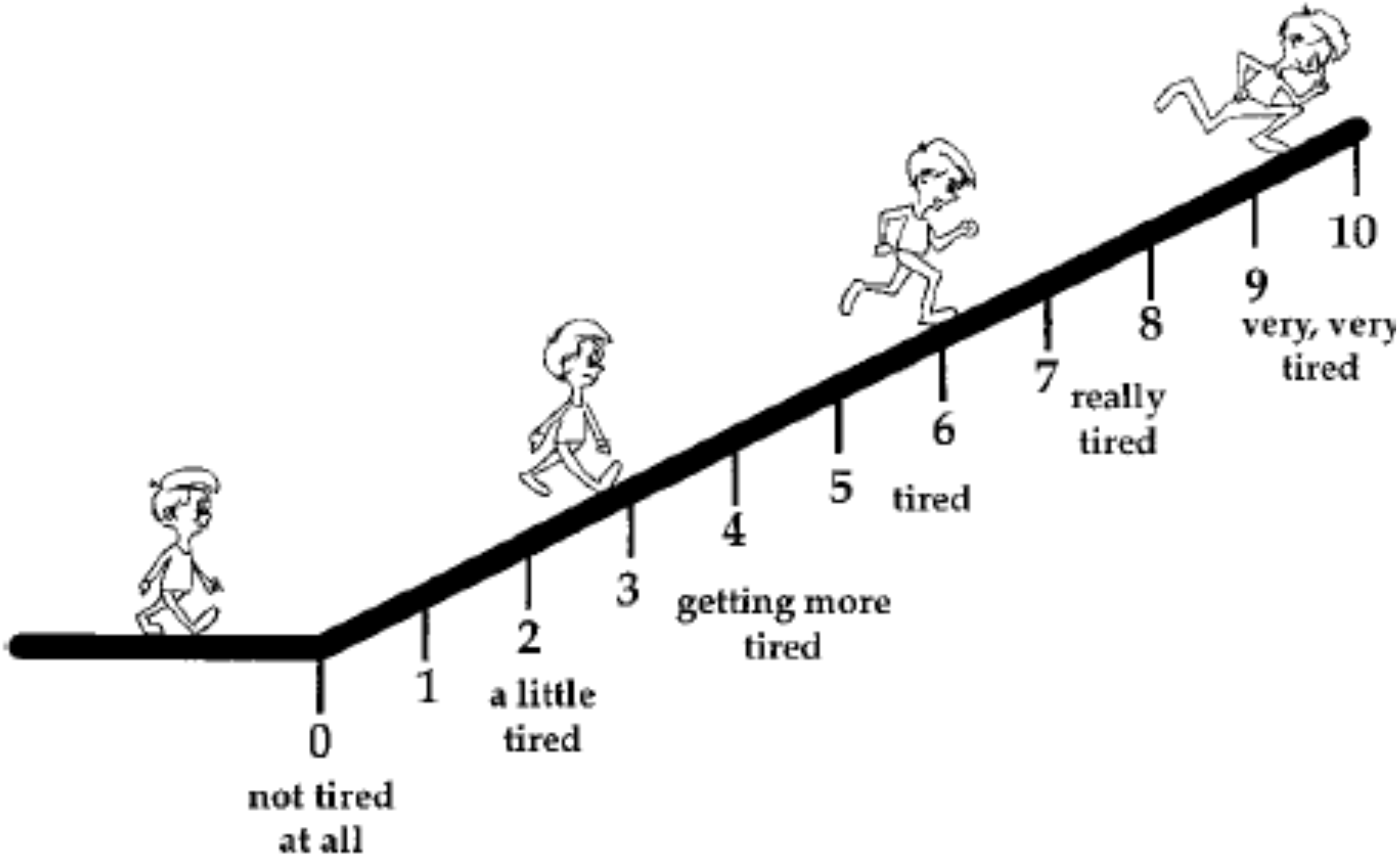

Figure 2 – OMNI walking/running scale, developed by Utter et al., 2002

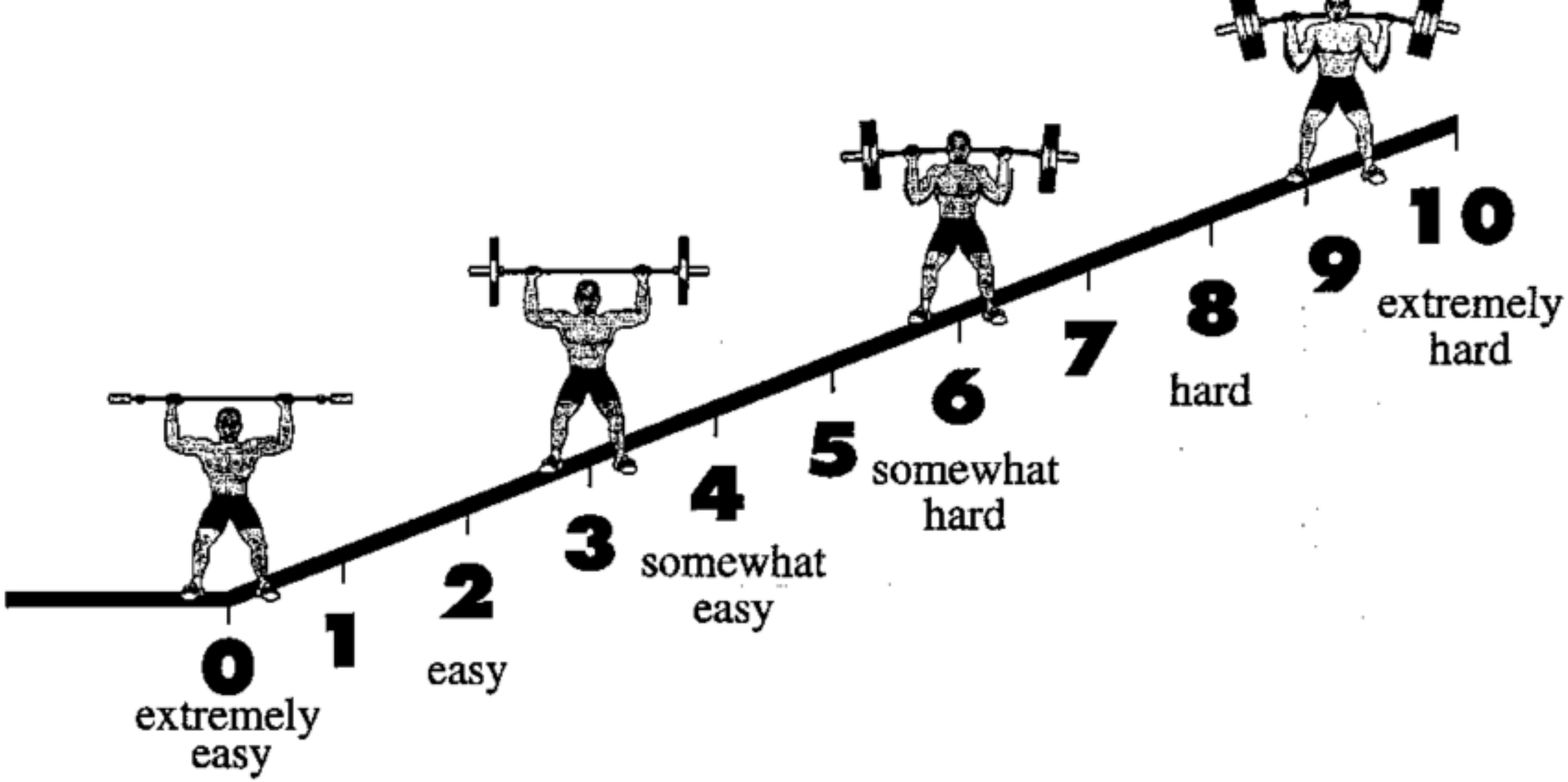

Figure 3 – OMNI resistance training scale, developed by Robertson et al., 2003

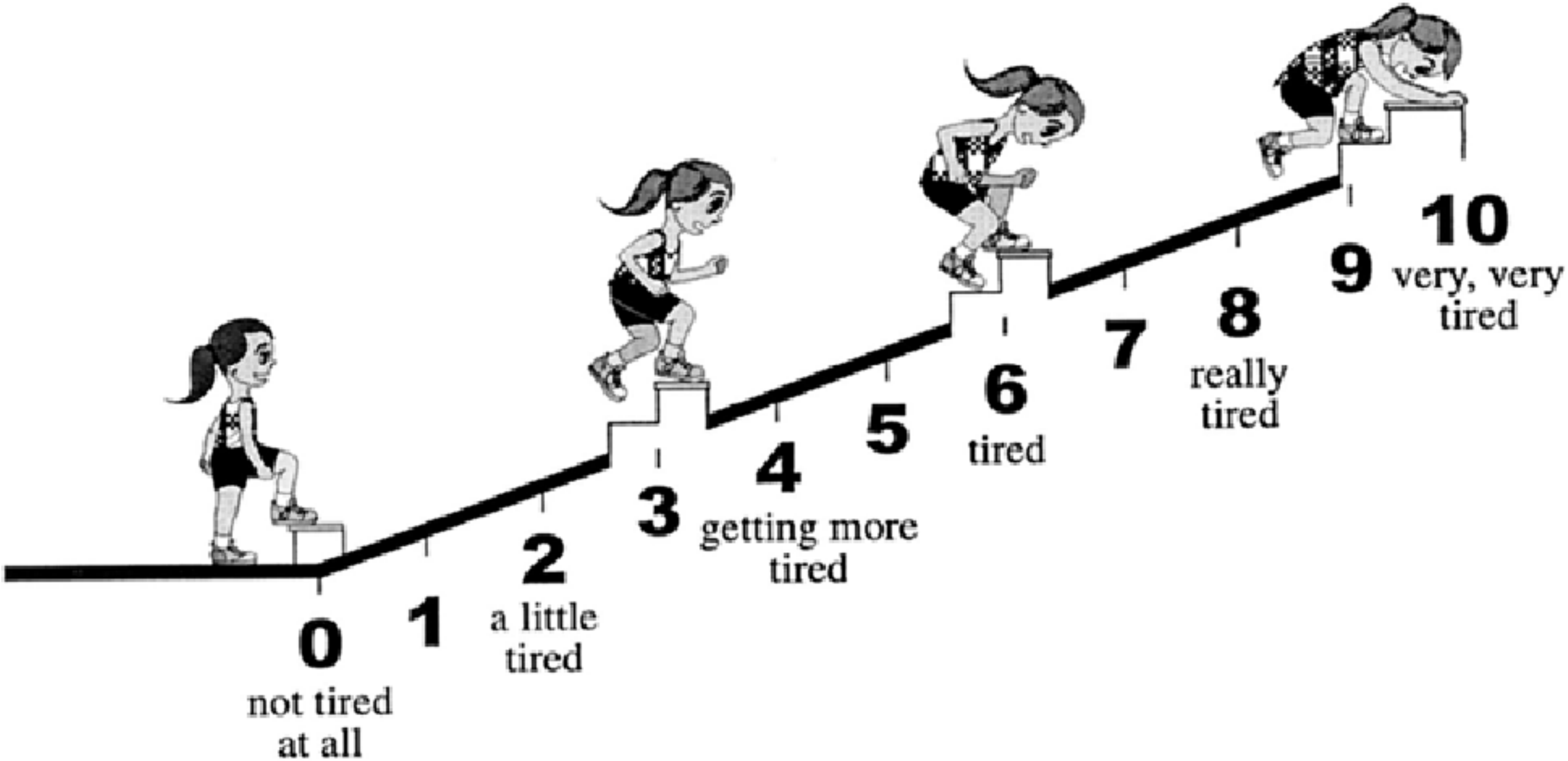

Figure 4 – OMNI stepping scale, developed by Robertson et al., 2005

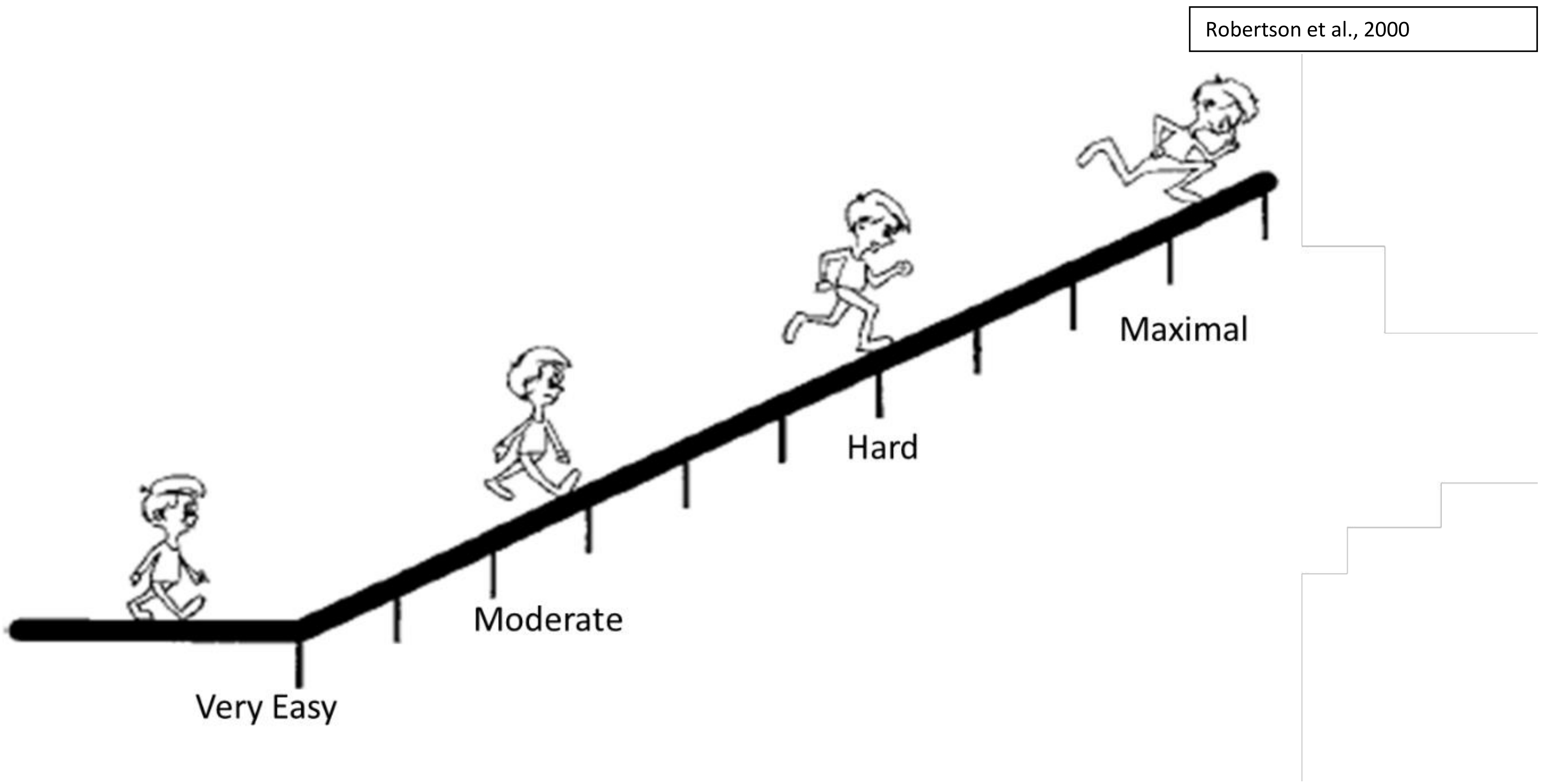

Figure 5 - Modified OMNI walking/running scale that accompanied the collection of dRPE. The verbal anchors associated at each point represent the same terminology used in the dRPE collection (Borg CR-100).

Table (7) Principal component analysis for the Post-PHV 1 vs Post-PHV 2 fixture on the small pitch size (17m x 17m).

Component Loadings			
	PC1	**PC2**	**PC3**
Total Distance			-0.805
Mean Heart Rate		-0.814	
RPE - CR10		0.884	
RPE - CR100	0.791	0.423	0.432
RPE-B - CR100	0.869		
RPE-L - CR100	0.856		
RPE-T – CR100	0.892		
Releases			0.877

Component loadings for each variable is displayed within each principal component it falls under.

Table (8) Principal component analysis for the Post-PHV vs Pre-PHV fixture on the small pitch size (17m x 17m).

Component Loadings			
	PC1	**PC2**	**PC3**
Total Distance		0.811	
Mean Heart Rate			0.980
RPE - CR10		0.762	
RPE - CR100	0.863		
RPE-B - CR100	0.840		
RPE-L - CR100	0.821		
RPE-T - CR100	0.613		
Releases	0.557		

Component loadings for each variable is displayed within each principal component it falls under.

Table (9) Principal component analysis for the Pre-PHV 1 vs Pre-PHV 2 fixture on the small pitch size (17m x 17m).

Component Loadings			
	PC1	**PC2**	**PC3**
Total Distance		0.707	
Mean Heart Rate		-0.725	
RPE - CR10		0.585	0.524
RPE - CR100	0.924		
RPE-B - CR100	0.824		
RPE-L - CR100	0.926		
RPE-T - CR100	0.895		
Releases			0.937

Component loadings for each variable is displayed within each principal component it falls under.

Table (10) Principal component analysis for the Mixed 1 fixture on the small pitch size (17m x 17m).

Component Loadings			
	PC1	**PC2**	**PC3**
Total Distance		0.760	
Mean Heart Rate		-0.545	
RPE - CR10		0.618	
RPE - CR100	0.785		
RPE-B - CR100	0.784		
RPE-L - CR100	0.757		
RPE-T - CR100	0.711		
Releases			0.958

Component loadings for each variable is displayed within each principal component it falls under.

Table (11) Principal component analysis for the Mixed 2 fixture on the small pitch size (17m x 17m).

Component Loadings			
	PC1	**PC2**	**PC3**
Total Distance		0.459	0.613
Mean Heart Rate			0.738
RPE - CR10			-0.630
RPE - CR100	0.442	0.649	
RPE-B - CR100	0.763		
RPE-L - CR100	0.878		
RPE-T - CR100	0.820		
Releases		0.907	

Component loadings for each variable is displayed within each principal component it falls under.

Table (12) Principal component analysis for the Mixed 3 fixture on the small pitch size (17m x 17m).

Component Loadings			
	PC1	**PC2**	**PC3**
Total Distance		-0.795	
Mean Heart Rate			0.777
RPE - CR10		0.815	
RPE - CR100	0.831		
RPE-B - CR100	0.947		
RPE-L - CR100	0.877		
RPE-T - CR100	0.866		
Releases		0.419	-0.801

Component loadings for each variable is displayed within each principal component it falls under.

Table (13) Principal component analysis for the Post-PHV 1 vs Post-PHV 2 fixture on the medium pitch size (24m x 24m).

Component Loadings			
	PC1	**PC2**	**PC3**
Total Distance		0.653	-0.628
Mean Heart Rate			0.944
RPE - CR10	0.808		
RPE - CR100	0.840		
RPE-B - CR100	0.819		
RPE-L - CR100	0.791		
RPE-T - CR100	0.952		
Releases		0.896	

Component loadings for each variable is displayed within each principal component it falls under.

Table (14) Principal component analysis for the Post-PHV vs Pre-PHV fixture on the medium pitch size (24m x 24m).

Component Loadings			
	PC1	**PC2**	**PC3**
Total Distance		-0.893	
Mean Heart Rate		0.528	-0.629
RPE - CR10	0.522		
RPE - CR100	0.822		
RPE-B - CR100	0.848		
RPE-L - CR100	0.802		
RPE-T - CR100	0.809		
Releases			0.819

Component loadings for each variable is displayed within each principal component it falls under.

Table (15) Principal component analysis for the Pre-PHV 1 vs Pre-PHV 2 fixture on the medium pitch size (24m x 24m).

Component Loadings			
	PC1	**PC2**	**PC3**
Total Distance			0.806
Mean Heart Rate	0.682		-0.408
RPE - CR10		0.832	
RPE - CR100	0.659		0.571
RPE-B - CR100	0.708		
RPE-L - CR100	0.707		
RPE-T - CR100		0.888	
Releases			0.692

Component loadings for each variable is displayed within each principal component it falls under.

Table (16) Principal component analysis for the Mixed 1 fixture on the medium pitch size (24m x 24m).

Component Loadings			
	PC1	**PC2**	**PC3**
Total Distance			0.819
Mean Heart Rate			0.696
RPE - CR10		0.641	
RPE - CR100	0.872		
RPE-B - CR100	0.771		
RPE-L - CR100	0.908		
RPE-T - CR100	0.941		
Releases		0.895	

Component loadings for each variable is displayed within each principal component it falls under.

Table (17) Principal component analysis for the Mixed 2 fixture on the medium pitch size (24m x 24m).

Component Loadings			
	PC1	**PC2**	**PC3**
Total Distance		-0.877	
Mean Heart Rate			0.942
RPE - CR10		0.877	
RPE - CR100	0.718	0.502	
RPE-B - CR100	0.817		
RPE-L - CR100	0.861		
RPE-T - CR100	0.932		
Releases	0.801		0.527

Component loadings for each variable is displayed within each principal component it falls under.

Table (18) Principal component analysis for the Mixed 3 fixture on the medium pitch size (24m x 24m).

Component Loadings				
	PC1	**PC2**	**PC3**	**PC4**
Total Distance		0.928		
Mean Heart Rate		0.937		
RPE - CR10	0.892			
RPE - CR100	0.942			
RPE-B - CR100			0.950	
RPE-L - CR100				0.810
RPE-T - CR100			0.882	
Releases				-0.818

Component loadings for each variable is displayed within each principal component it falls under.

Table (19) Principal component analysis for the Post-PHV 1 vs Post-PHV 2 fixture on the large pitch size (29.5m x 29.5m).

Component Loadings			
	PC1	**PC2**	**PC3**
Total Distance	0.889		
Mean Heart Rate		0.506	0.644
RPE - CR10		0.903	
RPE - CR100	0.631	0.694	
RPE-B - CR100	0.628	0.671	
RPE-L - CR100	0.880		
RPE-T - CR100	0.824		
Releases			0.899

Component loadings for each variable is displayed within each principal component it falls under.

Table (20) Principal component analysis for the Post-PHV vs Pre-PHV fixture on the large pitch size (29.5m x 29.5m).

Component Loadings			
	PC1	**PC2**	**PC3**
Total Distance	0.454		0.787
Mean Heart Rate		0.820	
RPE - CR10	0.682		-0.621
RPE - CR100	0.904		
RPE-B - CR100	0.874		
RPE-L - CR100	0.799		
RPE-T - CR100	0.850		
Releases		0.796	

Component loadings for each variable is displayed within each principal component it falls under.

Table (21) Principal component analysis for the Pre-PHV 1 vs Pre-PHV 2 fixture on the large pitch size (29.5m x 29.5m).

Component Loadings		
	PC1	**PC2**
Total Distance	0.564	
Mean Heart Rate		0.833
RPE - CR10	0.584	-0.462
RPE - CR100	0.898	
RPE-B - CR100	0.913	
RPE-L - CR100	0.913	
RPE-T - CR100	0.815	
Releases		0.689

Component loadings for each variable is displayed within each principal component it falls under.

Table (22) Principal component analysis for the Mixed 1 fixture on the large pitch size (29.5m x 29.5m).

Component Loadings		
	PC1	**PC2**
Total Distance		0.648
Mean Heart Rate		0.813
RPE - CR10	0.763	
RPE - CR100	0.890	
RPE-B - CR100	0.874	
RPE-L - CR100	0.756	
RPE-T - CR100	0.759	
Releases		0.610

Component loadings for each variable is displayed within each principal component it falls under.

Table (23) Principal component analysis for the Mixed 2 fixture on the large pitch size (29.5m x 29.5m).

Component Loadings		
	PC1	**PC2**
Total Distance		0.898
Mean Heart Rate		0.738
RPE - CR10	0.644	-0.476
RPE - CR100	0.915	
RPE-B - CR100	0.794	0.417
RPE-L - CR100	0.859	
RPE-T - CR100	0.865	
Releases	0.593	

Component loadings for each variable is displayed within each principal component it falls under.

Table (24) Principal component analysis for the Mixed 3 fixture on the large pitch size (29.5m x 29.5m).

Component Loadings			
	PC1	**PC2**	**PC3**
Total Distance		0.807	
Mean Heart Rate		0.914	
RPE - CR10	0.669		-0.462
RPE - CR100	0.914		
RPE-B - CR100	0.950		
RPE-L - CR100	0.776		
RPE-T – CR100	0.816		
Releases			0.863

Component loadings for each variable is displayed within each principal component it falls under.

Table (25) Principal component analysis for the Post-PHV 1 vs Post-PHV 2 fixture on the expansive pitch size (34m x 34m).

Component Loadings			
	PC1	**PC2**	**PC3**
Total Distance		0.807	
Mean Heart Rate	-0.520	0.546	
RPE - CR10	0.515	0.634	-0.524
RPE - CR100	0.785		
RPE-B - CR100	0.902		
RPE-L - CR100			0.917
RPE-T - CR100			0.848
Releases		-0.810	

Component loadings for each variable is displayed within each principal component it falls under.

Table (26) Principal component analysis for the Post-PHV vs Pre-PHV fixture on the expansive pitch size (34m x 34m).

Component Loadings			
	PC1	**PC2**	**PC3**
Total Distance			0.936
Mean Heart Rate		0.811	
RPE - CR10	0.631	0.459	
RPE - CR100	0.863		
RPE-B - CR100	0.837		
RPE-L - CR100	0.809		
RPE-T - CR100	0.778		
Releases		0.713	

Component loadings for each variable is displayed within each principal component it falls under.

Table (27) Principal component analysis for the Pre-PHV 1 vs Pre-PHV 2 fixture on the expansive pitch size (34m x 34m).

Component Loadings		
	PC1	**PC2**
Total Distance	0.867	
Mean Heart Rate		0.787
RPE - CR10		0.888
RPE - CR100	0.461	0.813
RPE-B - CR100	0.825	
RPE-L - CR100	0.785	
RPE-T - CR100	0.554	0.736
Releases	-0.741	

Component loadings for each variable is displayed within each principal component it falls under.

Table (28) Principal component analysis for the Mixed 1 fixture on the expansive pitch size (34m x 34m).

Component Loadings		
	PC1	**PC2**
Total Distance		0.526
Mean Heart Rate		-0.639
RPE - CR10	0.544	0.497
RPE - CR100	0.750	
RPE-B - CR100	0.874	
RPE-L - CR100	0.864	
RPE-T - CR100	0.830	
Releases		

Component loadings for each variable is displayed within each principal component it falls under.

Table (29) Principal component analysis for the Mixed 2 fixture on the expansive pitch size (34m x 34m).

Component Loadings			
	PC1	**PC2**	**PC3**
Total Distance		0.488	0.618
Mean Heart Rate		0.768	
RPE - CR10	0.844		
RPE - CR100	0.825		
RPE-B - CR100	0.823		
RPE-L - CR100	0.769	0.481	
RPE-T – CR100	0.725	0.457	
Releases			0.918

Component loadings for each variable is displayed within each principal component it falls under.

Table (30) Principal component analysis for the Mixed 3 fixture on the expansive pitch size (34m x 34m).

Component Loadings			
	PC1	**PC2**	**PC3**
Total Distance			-0.735
Mean Heart Rate		0.841	
RPE - CR10	0.882		
RPE - CR100	0.790	0.412	
RPE-B - CR100		0.775	
RPE-L - CR100	0.583	0.451	
RPE-T – CR100	0.942		
Releases			0.843

Component loadings for each variable is displayed within each principal component it falls under.

Table (31) Component characteristics for each fixture type on the small pitch size (17m x 17m).

Fixture	Principal Component	Eigenvalue
Post-PHV 1 vs Post-PHV 2	PC1	3.175
	PC2	1.911
	PC3	1.459
Post-PHV vs Pre-PHV	PC1	2.957
	PC2	1.328
	PC3	1.032
Pre-PHV 1 vs Pre-PHV 2	PC1	3.366
	PC2	1.669
	PC3	1.068
Mixed 1	PC1	2.644
	PC2	1.437
	PC3	1.050
Mixed 2	PC1	3.213
	PC2	1.386
	PC3	1.068
Mixed 3	PC1	3.571
	PC2	1.694
	PC3	1.152

The component characteristic displayed as the eigenvalue that forms each principal component for each fixture type.

Table (32) Component characteristics for each fixture type on the medium pitch size (24m x 24m).

Fixture	Principal Component	Eigenvalue
Post-PHV 1 vs Post-PHV 2	PC1	3.633
	PC2	1.573
	PC3	1.192
Post-PHV vs Pre-PHV	PC1	2.991
	PC2	1.389
	PC3	1.107
Pre-PHV 1 vs Pre-PHV 2	PC1	2.652
	PC2	1.690
	PC3	1.197
Mixed 1	PC1	3.626
	PC2	1.263
	PC3	1.101
Mixed 2	PC1	4.324
	PC2	1.413
	PC3	1.202
Mixed 3	PC1	3.139
	PC2	1.498
	PC3	1.360
	PC4	1.142

The component characteristic displayed as the eigenvalue that forms each principal component for each fixture type.

Table (33) Component characteristics for each fixture type on the large pitch size (29.5m x 29.5m).

Fixture	Principal Component	Eigenvalue
Post-PHV 1 vs Post-PHV 2	PC1	3.379
	PC2	1.594
	PC3	1.120
Post-PHV vs Pre-PHV	PC1	3.728
	PC2	1.322
	PC3	1.084
Pre-PHV 1 vs Pre-PHV 2	PC1	3.910
	PC2	1.395
Mixed 1	PC1	3.370
	PC2	1.460
Mixed 2	PC1	3.809
	PC2	1.732
Mixed 3	PC1	3.571
	PC2	1.891
	PC3	1.110

The component characteristic displayed as the eigenvalue that forms each principal component for each fixture type.

Table (34) Component characteristics for each fixture type on the expansive pitch size (34m x 34m).

Fixture	Principal Component	Eigenvalue
Post-PHV 1 vs Post-PHV 2	PC1	3.164
	PC2	1.927
	PC3	1.306
Post-PHV vs Pre-PHV	PC1	3.140
	PC2	1.430
	PC3	1.087
Pre-PHV 1 vs Pre-PHV 2	PC1	4.226
	PC2	1.769
Mixed 1	PC1	3.265
	PC2	1.200
Mixed 2	PC1	3.438
	PC2	1.497
	PC3	1.034
Mixed 3	PC1	3.454
	PC2	1.376
	PC3	1.161

The component characteristic displayed as the eigenvalue that forms each principal component for each fixture type.