TRAINING AND COMPETITION DEMANDS OF ADOLESCENT RUGBY UNION PLAYERS

Submitted by

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Statement of sources

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ABSTRACT

Background: An emerging trend in adolescent sport is a greater emphasis on identifying and developing talent in young athletes and improving articulation to elite adult participation. Adolescent athletes appear to be increasingly engaged in strenuous training processes thought to best serve these ends. The ability to adapt and recover from strenuous physical loading is finite and influenced by many unique factors during adolescence. Consequently, training and non-training stressors and, or, responses to stressors may exceed individual adaptation thresholds with deleterious, rather than beneficial outcomes. Undesirable consequences of training manifest in complex psychosociobiological signs and symptoms, often defined as overreaching or overtraining along the continuum of athlete adaption. For adolescents, undesirable training responses may impact normal growth and maturation, and athlete development, including participation and performance outcomes. In spite of known risks and increasing anecdotal comment on the adolescent athlete, the extent to which high loads of sports participation during adolescence are related to competitive success, serial fatigue, injury, and overtraining are profoundly under explored and knowledge to guide best practice is lacking. **Aims:** Within a framework of limited existing empirical evidence and in consultation with Australian Rugby Union, studies included in this thesis aimed to serially monitor participation among three levels of adolescent rugby union players to better understand factors contributing to positive performance and participation outcomes and minimising adverse effects including serial fatigue, injury, training errors, and overtraining in the context of the development of talented young athletes. **Methods:** For three separate studies, 75, 106, and 118 participants were recruited from various levels of adolescent rugby involvement that included, school, sports selective school, and state representative rugby. Subjective and objective measures of training volume and intensity, game and training practices, and stress and recovery were collected longitudinally. **Results:** In study one, representative squad players recorded the highest weekly duration of sport and physical activity (515 ± 222 min/week), followed by the talent squad (421 ± 211 min/week) and school boy group (370 ± 135 min/week). Profiles of individual players identified as group outliers showed weekly durations of 730 ± 49 min/week for a school boy player, 792 ± 226 min/week for a representative player, and 804 ± 335 min/week for a talent squad player, including up to three games and up to eleven training sessions per week for this individual. In study two, players with the highest weekly volume of sport and physical activity during the season demonstrated more favourable recovery-stress states compared with moderate and low volume groups. Despite better psychological stress and recovery profiles of more elite, higher load players, not all participants demonstrated favourable capacities to deal with stress and recovery processes. Seven of 106 participants were in at least two of three categories of highest volume, highest stress and poorest recovery. In study three, time-motion analyses showed that compared with rugby training, rugby games were consistently characterised by more time spent jogging (14 vs. 8%), striding (3.2 vs. 1.3%), and sprinting (1.3 vs. 0.1%) ($p<0.001$). Players also covered greater distances (4000 ± 500 vs. 2710 ± 770 m) and performed more sprints (21.8 vs. 1) during games compared with training ($p<0.001$). A major finding of this study is the disparity between physical game demands and on-field rugby training practices in adolescent players. **Discussion:** High-load participation demands of adolescent athletes may compromise optimal energy balance and compete with physiological, psychological, and time resources available for recovery. In team sports such as rugby, monitoring and quantifying load in individual athletes is necessary to facilitate best practice advice for player management and training prescription. It may be even more critical to monitor individual responses among adolescent athletes, in whom varied internal and external loads exist. Even in the absence of a complete understanding the impact of high volume, high stress, poor recovery participation, these markers may be precursors for more deleterious outcomes such as injury, performance decrements, and overtraining. Internal and external pressures, the transition from ‘sampling’ to ‘specialisation’, and over-exaggerated short-term performance goals may contribute to the high participation loads found in some adolescent rugby union players. **Conclusion:** Growth and maturation and adolescent sports’ participation create complex challenges for training and developing young athletes. Accumulative training and non-training stressors with inadequate recovery may exceed individual adaptation thresholds with deleterious, rather than beneficial performance and participation outcomes. It would be advantageous to identify ‘at risk’ individuals and appropriately manage adolescent athletes within redefined developmental frameworks that prioritise long-term goals, are cognisant of growth and maturation, and systematically aim to prescribe loads and recovery to avoid maladaptations.

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CHAPTER ONE

INTRODUCTION

1.1 Introduction

Participation in sport may be attractive to young people for a variety of reasons. Irrespective of individual athlete's motivation to participate, one of the roles of sporting organisations, coaches, and sports scientists is to facilitate fulfilling sporting experiences. Specifically, they are instrumental in ensuring players of all abilities enjoy the benefits of participating in organised sport as well as providing opportunities for talented young players to maximise performance potential and success. Perhaps driven by the professionalisation of many sports, an emerging trend in adolescent sport is a greater emphasis on identifying and developing talent in young athletes and improving articulation to elite adult participation. Adolescent athletes appear to be increasingly engaged in strenuous training processes thought to best serve these ends. However, in contrast to the plethora of research on sports science in mature athletes, research in adolescent sport is minimal.

On the continuum of athlete development, adolescents are encouraged to progress from the sampling years of participation to specialisation, with a principle goal of maximising performance in a single sport (Baker, Côté, & Abernethy, 2003; Côté, 1999). Such an approach is necessary to attain performance goals and is supported by theories of deliberate practice that purport a relationship between hours engaged in effortful, sport specific training (Ericsson, Krampe, & Tesch-Romer, 1993) and the level of performance achieved (Helsen, Starkes, & Hodges, 1998). Attaining expertise in sport is however, considerably more complex than this and is currently poorly understood in the adolescent context. Therefore, since pathways to intensive participation for elite athletes typically commence during adolescence and minimal empirical evidence exists to guide practice, an assessment of current approaches to the development of young athletes is warranted.

Broadly speaking, training to improve performance derives its success from the principle that a disturbance in homeostasis will ultimately cause a supercompensation effect and result in an addition to the previous threshold of stress tolerance. The operationalisation of this phenomena includes theories such as general adaption syndrome (Selye, 1950), fitness-fatigue model (Bannister, 1991), and physical stress theory (Mueller & Maluf, 2002). As it applies to sport, periods of stress (exercise and training) followed by periods of recovery typically result in improved future performances. However, since both adaptation and recovery are finite constructs, training and non-training stressors and, or, responses to stressors may exceed individual adaptation thresholds with deleterious, rather than beneficial outcomes. Undesirable consequences of training manifest in complex psychosociobiological signs and symptoms, often defined as overreaching or overtraining along the continuum of athlete adaption.

For adolescents, undesirable training responses may impact normal growth and maturation, participation in sport, as well as athlete development. Therefore, a major challenge for those working with young athletes is to determine the magnitude and nature of stressors necessary to induce positive responses and balance these with adequate recovery to avoid maladaptations (Hooper, Mackinnon, & Howard, 1999; Kellmann & Günther, 2000). Many unique challenges exist for achieving this in adolescent sport. Notably, the desire or pressure to achieve short-term goals of maximising playing opportunities and performances is difficult to balance with the process of adolescence and the many factors unique to this period of growth and development.

In spite of known risks and increasing anecdotal comment on the adolescent athlete, the extent to which high loads of sports participation during adolescence are related to competitive success, serial fatigue, injury, and overtraining are profoundly under explored and best practice advice is lacking. Therefore, thresholds of accumulative hours of competition and training need to be investigated within the context of markers of fatigue, illness, injury, and overtraining. Ideally, screening tools need to be devised from the most sensitive and practical field-based markers of maladaptation. It is anticipated that a better understanding of such markers as well as training approaches will assist in implementing systematic planning of training prescription to maximise performance outcomes and minimise adverse effects such as fatigue, injury, and overtraining among adolescent athletes. The profiling of adolescent participation in sports may therefore contribute to a better understanding of athlete development. More research on talent development in adolescents will also help nurture long-term and fulfilling participation by improving the scientific approaches used by sporting organisations, coaches, and sports scientists to develop young players.

1.2 Aims

General aim:

To serially monitor training and competition demands among adolescent rugby union players to better understand factors maximising performance outcomes and minimising adverse effects including serial fatigue, injury, training errors, and overtraining in the context of the development of talented young athletes.

Study one:

- Use notational analyses and self-reporting to define and serially monitor the participation loads associated with participation in rugby union.
- Define the variation in activity patterns for varying levels of participation.

Study two:

- Serially monitor psychological responses to participation in rugby by assessing the stress-recovery state of adolescent players relative to participation loads.
- Determine if a dose-response relationship of psychological markers to participation loads exists among adolescent rugby union players.

Study three:

- Use time-motion analyses to describe and compare game demands and on-field training practices of adolescent rugby union players, including positional differences.
- Understand factors contributing to training errors that may increase athlete risk of deleterious outcomes of participation.

1.3 Hypotheses

General hypothesis:

Adolescent participation in team sport will be characterised by many unique factors that contribute to positive and negative adaptations in response to training processes associated with participation in rugby union.

Study one:

- Participation loads associated with adolescent athletes will be ‘high’.
- Participation loads and participation patterns will vary according to level of play.
- Adolescent participation patterns will differ from known adult athlete participation patterns

Study two:

- Psychological markers of stress and recovery will be evident among some individual athletes exposed to high participation loads.
- A dose-response relationship will exist between psychological markers of stress and recovery and participation loads.

Study three:

- Physical demands of games will be greater and then on-field training demands and on-field training will lack game specificity.
- Some training practices will not be optimal for the development of adolescent athletes and may contribute to risks of maladaptation.

1.4 Limitations

The following limitations have been acknowledged:

- Matching groups of players for ability, training phase and training practices is a major challenge for field-based research. Differences in groups included in this thesis might have influenced the studies' dependent variables.
- Time-motion analyses undertaken in this study did not extend to measures of frequency of skilled movements such as tackles, kicks, and scrums, activities which contribute significantly to total playing exertion.
- Time-motion analysis techniques used in this study continue to demonstrate some systematic errors.
- Player participation loads outside of rugby union were subjectively determined using self-reporting methods. Training diaries and compliance with diaries remain imperfect and may have been erroneous in determining participation loads.
- The generalisability of some results may have been limited since participants were delimited to a single sport and a single gender.
- Maturational status was not determined. Variations in maturation may have influenced perceptions and adaptations to stress, recovery, and participation demands.
- Nutrition and recovery practices were beyond the scope of the study but may have influenced athletes training, performance, and recovery.

1.5 Delimitations

The following delimitations were applied:

- Participation was restricted to males.
- Participants were aged between 14 and 18 years.
- Recruited players had to be participating in rugby union including training and matches at time of recruitment.
- Participants had to be free of injury to the extent that they were still able to play and train in the month prior to recruitment.
- Time-motion analyses data collected during training and games needed to be more than 10 minutes in duration to be included in analyses.
- Game and training measures for physical loads differed because it was not possible to use GPS tracking devices during competitive games. Therefore the study was delimited to two related but separate methods of monitoring performances in training and games.
- The maximum number of players monitored during training and games was delimited to the number of available GPS units and video cameras.
- Adolescent athletes were delimited to three levels of participation (school boy rugby, selective school's high performance squads, and state representative teams).

1.6 Definitions

Adolescence: period between childhood and adulthood coinciding with physical and mental development involving biological, psychological and behavioural changes (Tanner, 1978).

Training volume: volume of training in minutes or hours usually summated for all sessions and represented as a weekly volume.

Training Intensity: intensity of training determined using both internal (rate of perceived exertion and heart rate) and external (running velocities and sprinting patterns) measures of intensity.

Training load: reflects the product of volume (duration) and intensity (internal and external) of training.

Participation loads: the volume (duration) and intensity (internal and external) of rugby training, rugby games and all other sport and physical activity undertaken by participants in this study.

Fatigue: a generic term referring to an inability of any number of systems or combination of systems in the body to repeat or maintain physical work demands caused by a number of known and unknown factors.

Overreaching: an accumulation of training and, or, non-training stressors that result in short-term decrements in performance with or without the presence of physiological and psychological signs and symptoms of maladaptation in which restoration of performance capacity can be restored within days to weeks (Kreider, Fry, & O’Toole, 1998).

Functional overreaching: short-term overreaching deliberately utilized during training cycles where intensive training that results in transient decreases in performance is followed by a supercompensation effect and a better than baseline performance capacity after a recovery period (Halson & Jeukendrup, 2004; Meeusen, Duclos, Gleeson, Rietjens, Steinacker, & Urhausen, 2006; Steinacker, Lormes, Reissnecker, & Lui, 2004; Urhausen & Kindermann, 2002).

Non-functional overreaching: point along a continuum in which short-term overreaching results in more persistent decreases in performances that can be restored to baseline, but where a supercompensation effect following recovery is often not observed (Halson & Jeukendrup, 2004; Meeusen et al., 2006; Moore & Fry, 2007; Urhausen & Kindermann, 2002).

Overtraining (classical): an accumulation of training and, or, non-training stressors that result in long-term decrements in performance with or without the presence of physiological and psychological signs and symptoms of maladaptation in which restoration of performance capacity can be restored within weeks to months (Kreider et al., 1998).

Burnout: a psychological syndrome of emotional / physical exhaustion, reduced sense of accomplishment, and sport devaluation, associated with intense demands of participation in sport – the effect may ultimately result in complete withdrawal from participation (Raedeke & Smith, 2001; Smith, 1986).

Time-motion analysis / notational analysis: objective quantification of sport-specific movement patterns including activities, duration, speed, and distance for different locomotive patterns observed during games and training.

Global Positioning System (GPS): time-motion analysis technique that uses signals from earth orbiting satellites and a GPS receiver to compare differences in measured time (internal satellite and receiver clocks) and time for signal travel to calculate distance and then triangulate receiver location and subsequently derive movement data (Larsson, 2003; Witte & Wilson, 2004).

Computer based tracking (CBT): time-motion analysis technique using video footage that permits the simulation real time movements of participants by observing and "tracking" player's locomotive movements on a scaled version of a playing field superimposed on a drawing tablet in conjunction with appropriate software.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 Adolescents and Exercise

2.1.1 Introduction

In the context of contemporary sports participation, adolescent athletes are less frequently viewed as small adults. It is paramount that such a view continues to grow in acceptance. The unique characteristics that define the period of adolescence between childhood and adulthood, particularly with reference to participation in sport will therefore, be discussed in the following section.

Intensive participation in sport is increasingly common among adolescent athletes. Current knowledge of adolescents and exercise however, has been limited by several factors. Much of the research has focused on children compared with adults and less on the period of adolescence. Many assumptions about adolescent exercise responses have been made by inferring findings from research among adults and children. Furthermore, accelerated maturational changes during adolescence make research and interpretation of results in this population challenging. Profound growth and maturation changes occur during puberty and the potential impact on sports participation warrants consideration. Concomitantly, the trainability and performance of adolescents compared with children and adults, and specific injury considerations are also worthy of discussion. Discussions will largely be limited to males, given their predominance in the majority of existing literature and their relevance to this thesis.

2.1.2 Male adolescent growth and maturation

Absolute growth in human tissue from prenatal to mature development progresses in a more or less continuous fashion. Velocity of growth is not continuous and fluctuates with advancing age, while also exhibiting great variability in timing and tempo. The most notable of these fluctuations is the onset of puberty. Pubertal growth occurs under the biological control of the neuroendocrine system and results in accelerated physical, physiological, and psychological changes that advance the process of maturation (Tanner, 1978). The onset of puberty is determined by genetic and environmental factors (Kimura, 1983; Zacharias & Wurtman, 1969) and is denoted by the development of secondary sex characteristics, accelerated linear growth, as well as changes in body composition (Rogol, 1994). Many alterations in cellular physiology and neuroendocrine function are less obvious, but are of equal importance (Boisseau & Delamarche, 2000).

2.1.2.1 Growth, maturation, and puberty

In males, secondary sex characteristics include growth in the testes and penis, appearance of facial, body, and axillary hair, and a lowering of the pitch of the voice due to elongation of vocal chords (Tanner, 1978). Increased testicular volume is usually the first sign of true central puberty in boys (Baxter-Jones, Eisenmann, & Sherar, 2005). Pubic hair development may precede testicular growth, however, the development of pubic hair represents onset of adrenarche rather than true puberty (Tanner, 1962). To further assist in describing maturation occurring at puberty, secondary sex characteristic changes for genitalia and pubic hair growth have been classified into distinct stages along a continuum from 1 to 5 (Reynolds & Wines, 1951; Tanner, 1978). While useful, ‘Tanner staging’ requires either direct observation by researchers or self-reporting to determine maturational status (Schmitz, Hovel, Nichols, Irvin, Keating, Simon, Gehrman, & Jones, 2004). Direct and proxy assessments of pubertal status can be problematic, but nevertheless provide critical information in adolescent research.

Monitoring of the greatest rate of growth in height (peak height velocity) during late childhood and early adolescence is also useful in determining maturational status. Somatic growth and growth in height in particular do not increase linearly. Peak height velocity can therefore, easily be determined from a velocity growth curve. In males, a peak height velocity of about 9.5 cm/year usually occurs at Tanner stage 3 to 4 corresponding to approximately age 13 or 14 years (Abbassi, 1998). However, large timing and tempo variability exists in the onset of pubertal growth and the rate of progression towards maturity (Baxter-Jones et al., 2005; Plowman, 1989).

In addition to accelerated growth in height during the circumpubertal years, other tissues exhibit a corresponding growth spurt. Body composition alters such that in males, large gains in fat free mass are experienced as muscle tissue hypertrophies (Allen, Merkel, & Young, 1979; Siervogel, Maynard, Wisemandle, Roche, Guo, Chumlea, & Towne, 2000). Fat free mass in males has been shown to increase between the ages of 8 and 18 years, with most rapid increases occurring between the ages of 12 and 15 years (Siervogel, Demerath, Schubert, Remsberg, Chumlea, Sun, Czerwinski, & Towne, 2003). In both genders, fat mass increases during growth and accelerates during puberty. However, increases are smaller in males than females and boys will typically accrue an additional 4% body fat mass between the ages 6 and 17 years (Malina & Bouchard, 1991). The accrual of fat mass and fat free mass during growth is important since both tissues are endocrinologically active and contribute to normal adult hormone regulation and metabolism (Holst & Grimaldi, 2002; Horlick, Rosenbaum, Nicolson, Levine, Fedun, Wang, Pierson, & Leibel, 2000).

Bone tissue (or cartilage its precursor) also undergoes puberty-related growth and largely accounts for rapid changes in height and limb length. During normal growth, cartilaginous models of bone undergo ossification with a resultant change in length, breadth and shape of the skeletal system (Tanner, 1978). An estimated 50% of the total bone mineral of the adult skeleton is attained during the second decade of life, the pubertal growth spurt accounting for most of that accrual (Katzman, Bachrach, Carter, & Marcus, 1991). Puberty-related signalling particularly at the epiphyseal plates advances the maturation of the skeletal system (Rogol, 2007). An assessment of skeletal age or skeletal maturity is therefore, possible by examining the degree of bone ossification and fusion at the epiphyses (Roche, 1988). Skeletal age is highly variable. In 13 and 14 year old males, skeletal ages between 9 and 16 years have been measured (Kemper & Verschuur, 1981). Large discrepancies also exist in the assessment of skeletal age using X-ray from different sites (Roche, Wainer, & Thissen, 1975). Nevertheless, in addition to secondary sex characteristics and somatic growth, skeletal age provides a more accurate assessment of progress toward full maturity than chronological age alone.

Variability in the timing and tempo of the aforementioned maturation processes is well established and has multiple implications. Timing refers to the age at which specific maturational markers commence, for example the age at which peak height velocity is observed. Tempo is the rate at which these maturational processes progress (Malina, Bouchard, & Bar-Or, 2004). Some children might start pubertal-related growth and maturation considerably earlier or later than the mean age and could move through stages either slowly or quickly. Even within individuals, somatic growth, secondary sex characteristics and skeletal age, while typically highly interrelated (Malina, 1978; Marshall, 1974), show variability in tempo and timing (Bailey, 1997; Marshall & Tanner, 1970). Tempo and timing differences therefore, necessarily result in early and late developing children. Early developers among males may be advantaged in sport, benefiting from comparatively greater size and muscle mass and improved functional capacities compared with age-matched peers (Naughton, Farpour-Lambert, Carlson, Bradney, & Van Praagh, 2000).

2.1.2.2 Hormonal regulation of puberty

The physical changes occurring during puberty are moderated by complex neuroendocrine control mechanisms. Two independent but temporally linked mechanisms, adrenarche and gonadarche establish the hormonal milieu necessary for growth and maturation during puberty (Grumbach, 2002). Adrenarche is the increase in adrenal androgen synthesis and secretion and usually occurs between 8 and 10 years of age in Caucasian boys. Gonadarche follows by approximately 2-3 years in males and is defined as the activation of the testes. Gonadarche represents onset of true central puberty (Boisseau & Delamarche, 2000). Ultimately, it is the central nervous system that activates and controls the phenomena of adrenarche and gonadarche, though many questions remain about mechanisms and triggers. In the first instance, the activation of the hypothalamic-pituitary-adrenal axis results in increases in adrenal androgens dehydroepiandrosterone (DHEA) and dehydroepiandrosterone-sulphate (DHEAS) (Plowman, 1989). In the second, there is a reactivation of the hypothalamic-pituitary-gonadotropin-gonadal axis (Grumbach, 2002).

Reactivation of the hypothalamic-pituitary-gonadotropin-gonadal axis, active in infancy and then quiescent in childhood is necessary to attain sexual maturity. The period of hypothalamic neuroendocrine inactivity, referred to as the ‘juvenile pause’ is likely the result of central nervous system inhibition by several mechanisms (Grumbach, 2002). At puberty a disinhibition of the previously suppressed hypothalamic regions responsible for producing the hormones necessary for pubertal growth and maturation heralds the onset of central puberty and progress towards sexual maturation. In sexually mature adults, reproductive function is controlled by luteinising hormone (LH) and follicle stimulating hormone (FSH) released from the pituitary. Their release requires stimulation by luteinising hormone-releasing hormone (LHRH), also known as gonadotropin-releasing hormone (GnRH), produced in the hypothalamus (Styne, 2003). Pulsatile releases of LHRH increase in amplitude at puberty and result in much greater serum levels of gonadotropins LH and FSH (Dunkel, Alfthan, Stenman, Selstam, Roseberg & Albertsson-Wikland, 1992), which in turn, act on the testes to produce sperm cells and testosterone.

Gonadal and adrenal glands, now capable of increased secretions of sex hormones mediate puberty-related growth changes (Martha, Gorman, Blizzard, Rogol, & Veldhuis, 1992) along with increased levels of growth hormone (GH), insulin-like growth factor-1 (IGF-1), leptin, insulin, and estradiol (Boisseau & Delamarche, 2000). Pituitary secretions of GH increase during puberty and tend to strongly correlate with the pubertal growth spurt (Mauras, Blizzard, Link, Johnson, Rogol, & Veldhuis, 1987). Growth hormone mediates growth in bone and muscle tissue, in particular, through its effect on IFG-1. Growth hormone and thus IGF-1 interact with gonadal sex hormones to collectively bring about the pubertal growth spurt (Mauras, 2001). Originally testosterone was believed to be the most important sex hormone involved in this process. However, it appears estradiol exerts the major effect (Grumbach, 2000), with the involvement of testosterone, seemingly limited to its aromatisation to estradiol (Styne, 2003).

The hormones insulin and leptin may also play critical roles during pubertal growth. Insulin resistance increases during puberty (Amiel, Caprio, Sherwin, Plewe, Haymond, & Tamborlane, 1991; Cook, Hoffman, Stene, & Hansen, 1993), resulting in higher than prepubertal serum insulin levels. The increased resistance however, appears to be limited to peripheral glucose metabolism, thereby not influencing metabolism of the remaining macronutrients. Postulations on the role of insulin during intensive growth suggest the relative hyperinsulinaemia during puberty may actually support growth by increasing the availability of IGF-1, important for anabolic activity (Caprio, 1999). Puberty-related growth changes might also be influenced by the adipocyte hormone leptin (Demerath, Towne, Wisemandle, Blangero, Chumlea, & Siervogel, 1999; Grumbach, 2002). Leptin is principally produced in adipocyte tissue. It increases with increased adiposity and acts on the hypothalamus to suppress appetite (Styne, 2003). Leptin levels rise during puberty, but in males, later become suppressed as a result of rising serum levels of androgens (Blum, Englaro, Hanitsch, Juul, Hertel, Muller, Skakkerbaek, Heiman, Birkett, Attanasio, Kies, Rascher, 1997). Since leptin administered to normal rodents failed to initiate puberty (Cheung, Clifton, & Steiner, 2000), rising leptin levels appear to be ‘permissive’ during puberty perhaps informing other triggering mechanisms that adequate energy stores exist for puberty to commence (Grumbach, 2002; Naughton et al., 2000).

2.1.3 Trainability in male adolescents

By virtue of physical growth and maturation, functional capacities and consequently athletic performance improve at and during adolescence (Baxter-Jones et al., 2005). Growth and maturation-related improvements in physical ability during puberty make understanding the independent effects of training challenging. Additionally, changing patterns of habitual physical activity and sports participation may confound adolescent research, even when these variables are accounted for. Nevertheless, researchers have attempted to investigate the trainability of adolescents. Improved athletic performance can be the result of any, or a combination of many trainable and non-trainable factors. In adolescents participating in team sports, the most pertinent physical training factors are; improved aerobic capacity, anaerobic capacity, strength, and power.

2.1.3.1 Aerobic capacity

Endurance performances are primarily limited by aerobic capacity which can be determined using a number of physiological measures. In adults, maximal oxygen consumption ($\dot{V}O_{2max}$), running economy, and lactate / ventilatory thresholds are frequently used to assess aerobic capacity (Jones & Carter, 2000). Similarly, in children and adolescents, peak oxygen consumption ($\dot{V}O_{2peak}$), lactate threshold and economy of energy expenditure are well established characteristics of endurance performances (Pate & Ward, 1996). Aerobic adaptations to training are well documented among adults who consistently demonstrate good adaptability in both central and peripheral systems involved in oxygen delivery and utilisation (Wilmore, Stanforth, Gagnon, Rice, Mandel, Leon, Rao, Skinner, & Bouchard, 2001). In adults, improvements in aerobic capacity arising from central and peripheral adaptations include increased cardiac output (Q), improved arteriovenous oxygen difference (A-$\dot{V}O_2$ difference), and improved oxidative efficiency. Whether aerobic adaptations in adolescents occur by the same mechanisms is uncertain (Matos & Winsley, 2007).

In spite of acknowledged limitations to the usefulness of peak $\dot{V}O_2$ for predicting endurance performance, particularly in younger athletes (Matos & Winsley, 2007), a majority of research has used changes in this measure to assess aerobic trainability. Adults engaged in aerobic training can typically expect improvements in peak $\dot{V}O_2$ of around 15-20% (Bouchard, Dionne, Simoneay, & Boulay, 1992). The magnitude of improvement however, is dependent on several variables including individual variability, initial fitness level, compliance with training, and type and quality of training. In children, cross-sectional and longitudinal research has shown either no improvements (Kobayashi, Kitamura, Miura, Sodeyama, Murase, Miyashita, & Matsui, 1978; Mirwald, Bailey, Cameron, & Rasmussen, 1981) or improvements of smaller magnitude than in adults (Pate & Ward, 1996, Rowland, 1985; Shephard, 1992) in measures of aerobic capacity. Compared with adults, children's higher activity levels and higher initial peak $\dot{V}O_2$ partly explain their lower trainability (Shephard, 1992), but other mechanisms, yet to be identified most likely also contribute.

Much less is known about aerobic adaptations in adolescent athletes. A recent review on endurance training in young athletes noted the considerable lack of research among circumpubertal individuals compared to research on children (Baquet, Van Praagh, & Berthoin, 2003). Despite limited data, it is generally accepted that training during the circumpubertal years can improve aerobic capacity. Studies reviewing the trainability of younger athletes generally concluded peak $\dot{V}O_2$ improvements between 5 and 10% in children (Baquet et al., 2003; Matos & Winsley, 2007; Pate & Ward, 1996; Payne & Morrow, 1993). Research has however, produced conflicting results with regards to the magnitude of the training effect during puberty.

The authors of one review concluded that aerobic trainability became compromised during puberty compared with pre and post puberty trainability (Pate & Ward, 1996). In a twin study of pubescent boys 10, 13, and 16 years of age where one twin performed aerobic training and the other served as a control, $\dot{V}O_{2peak}$ improvements were up to 5% smaller in the midpubescent group compared with pre and postpubescent groups (Weber, Kartodihardjo, & Klissouras, 1976). Subsequent research findings do not support the notion of decreased aerobic training sensitivity during puberty (Hansen & Klausen, 2002; Kraemer, Acevedo, Synovitz, Herbert, Gimpel, & Castracane, 2001; McMillan, Helgerud, Macdonald, & Hoff, 2005; Plank, Hipp, & Mahon, 2005; Rowland, Varzeas, & Walsh, 1991), though trainability remains lower than in adults. Moreover, the ‘trigger hypothesis’ (Katch, 1983) suggests that a marked increase in trainability coincides with maturation occurring during puberty, particularly in males for whom hormonal changes become permissive for training adaptations.

Increased efficiency in aerobic metabolism as well as central adaptations to oxygen delivery is necessary for improved aerobic capacity. The adaptations occurring in adolescent athletes that demonstrate improved aerobic capacity are mostly similar to those occurring in adults, though some differences are evident. In adults, increased Q arises from increased stroke volume (SV) and ventricular size (Wilmore et al., 2001). The same adaptations that account for improved Q in adults appear to explain improved Q in young athletes. Following 13 weeks of aerobic training in prepubertal (10.5 ± 0.3 years) participants, a significant increase in SV (and therefore, Q) was the strongest explanatory variable for the large improvements observed in $\dot{V}O_{2peak}$ (Obert, Mandigout, Nottin, Vinet, N'Guyen, & Lecoq, 2003). Testosterone plays a crucial role in the development of increased SV through its anabolic effects on cardiac tissue (Janz, Dawson, & Mahoney, 2000). Pubertal athletes can therefore, expect significant benefits to cardiovascular function as a result of growth-related increases in testosterone.

In addition, or even in the absence of changes to $\dot{V}O_{2peak}$, adolescent athletes have demonstrated trainability in other measures of aerobic capacity. At similar relative intensities lactate production is lower in adolescents than in adults (Kuno, Takahashi, Fujimoto, Akima, Miyamura, Nemoto, Itai, & Katsuta, 1995). Exercise intensities that elicit highest steady state lactate levels (lactate threshold) have therefore, been shown to correspond to a higher percentage of $\dot{V}O_{2peak}$ in adolescents compared with adults (Tolfrey & Armstrong, 1995). Steady state lactate levels have however, been shown to be more related to training status than age alone (Beneke, Heck, Schwartz, & Leithauser, 1996), and adolescents have improved lactate thresholds even when $\dot{V}O_2$ remained unchanged (Haffor, Harrison, & Kirk, 1990). Adolescents may be less efficient at energy expenditure than adults, expending more energy for similar external work (Harrell, McMurray, Baggett, Pennell, Pearce, & Bangdiwalla, 2005; Walker, Marray, Jackson, Morrow, & Michaud, 1999). Energy expenditure inefficiencies may arise from differences in running mechanics that improve with developing age (Rowland & Cunningham, 1992). As with other predictors of endurance performance, efficiency of movement may improve in response to training over and above growth-related improvements (Naughton et al., 2000).

Metabolic, haematological, and hormonal adaptations to aerobic training that result in improved efficiency in oxidative metabolism support the notion that adolescents are well equipped to adapt to training (Boisseau & Delamarche, 2000). Hormonal changes particularly in testosterone and GH during puberty have been correlated with improved aerobic trainability in adolescents (Rowland, 1997). Similar to the response in adults, testosterone increases during chronic training and may increase as much as threefold in young athletes (Mero, Jaakkola, & Komi, 1990), further supporting the notion of sensitivity to training during puberty. Plasma volume, including hematocrit and haemoglobin levels show similar positive adaptations to training during puberty and adulthood (Fahey, Del Valle-Zuris, Oehlsen, Trieb, & Seymour, 1979; Hansen & Klausen, 2002) and mitochondrial size and number appear similar in children and adults (Bell, MacDougall, Billeter, & Howard, 1980). Oxidative enzymatic adaptations including increased concentrations of succinate dehydrogenase and isocitrate dehydrogenase that occur in adult endurance athletes have also been shown to increase in children and adolescents post training (Eriksson, Gollnick, & Saltin 1973; Haralambie, 1982).

Muscle glycogen, substrate usage, and respiratory exchange ratio (RER) may differ in adolescents and adults. Research evaluating muscle glycogen content and depletion in adolescents is limited, presumably because of ethical concerns related to muscle biopsy procedures in young participants (Boisseau & Delamarche, 2000). Two studies have however, demonstrated lower glycogen content in adolescents and subsequently postulated more rapid depletion during prolonged exercise compared with adults (Eriksson, Karlsson, & Saltin, 1971; Ericsson et al., 1973). Research investigating substrate usage has been conflicting. Nevertheless, it appears children and adolescents rely more on fatty acids than adults (Boisseau & Delamarche, 2000), sometimes (Martinez & Haymes, 1992; Timmons, Bar-Or, & Riddell, 2002) but not always (Macek, Vavra, & Novosadova, 1976) supported by lower RER values.

The magnitude of adaptations to aerobic capacity depends on the specific training approach used. An extensive review on research investigating the trainability of children and adolescents including the frequency, duration, length of intervention, type, and intensity of protocol used, concluded that improvements in $\dot{V}O_2$ were independent of training frequency, duration, and length of program. Exercise intensity however, was a key predictor of improvements in $\dot{V}O_2$ and most evidence suggested that children and adolescents require intensities in excess of 80% HR_{max} to elicit adaptations (Baquet et al., 2003; Matos & Winsley, 2007). In summary, significant improvements in aerobic capacity can be achieved during puberty though the magnitude of changes remains lower than in adults and the intensities required to stimulate adaptations appear higher. Adolescents demonstrate aerobic trainability via many of the same adaptations that occur in adults but may differ in storage and usage of substrates such as muscle glycogen and fatty acid oxidation, and lactate production is consequently also altered. Adolescent males appear especially well suited to aerobic training. Physical growth and hormonal maturation during puberty contribute to improved aerobic capacity independent of training. However, when training is undertaken during puberty, growth, maturation, and development may create a permissive environment for further improvements.

2.1.3.2 Anaerobic capacity

The ability to produce large amounts of force quickly (power) is essential for performances in team sports. Anaerobic power is the maximal ATP production per second via anaerobic bioenergetic pathways during short duration, maximal intensity efforts (Green, 1994). The rate of ATP production in response to intense exercise is affected by complex interactions between several variables. Muscle fibre type, specific rate limiting enzymes, muscle mass, muscle substrate availability, neuromuscular activation, motivation, coordination, and muscle metabolism including the efficiency of phosphocreatine and anaerobic glycolytic pathways determine ATP production and thus anaerobic capacity (Ratel, Duché, & Williams, 2006; Van Praagh, 2000).

In adults, the trainability of anaerobic power and capacity has been repeatedly demonstrated (Barnett, Carey, Proietto, Cerin, Febbraio, & Jenkins, 2004). Current understanding of anaerobic trainability during adolescence is not as well established and has been hindered by limitations in the ability to define and measure anaerobic performances as well as ethical constraints in collecting data from young participants (Van Praagh & Doré, 2002). Gold standard measures do not exist for anaerobic performances. Consequently, definitions and measuring techniques are often varied and debated. Historically, invasive methods such as muscle biopsy were necessary to investigate cellular and biochemical adaptations to anaerobic training which often precluded studies among children and adolescents. More recently, advances in non-invasive techniques such as phosphorus-31 nuclear magnetic resonance spectroscopy (^{31}PNMR) (Sapega, Sokolow, Graham, & Chance, 1987) have facilitated studies of muscle bioenergetics in younger populations (Barker, Welsman, Welford, Fulford, Williams, & Armstrong, 2006; Boisseau & Delamarche, 2000; Cooper & Barstow, 1996; Kuno et al., 1995; Ratel, Tonson, Le Fur, Cozzone, & Bendahan, 2008).

Relative to weight (body or muscle), power production during anaerobic efforts is lower in adolescents than in adults (Van Praagh, 2000). These differences reduce with increasing age particularly in boys where anaerobic performances as well as muscle and biochemical adaptations increase substantially during adolescence (Armstrong, Welsman, & Chia, 2001; Ratel et al., 2006; Van Praagh, 2000; Williams, 1997). Recently, maximal power output during short-term cycle tests was shown to increase with age in prepubertal, pubertal, and postpubertal groups matched for anthropometric characteristics (Martin, Doré, Hautier, Van Praagh, & Bedu, 2003). Since groups had similar lean tissue, improvements were attributed to qualitative (muscle fibre type, anaerobic energy production, and neural and motor pattern factors) rather than quantitative changes in muscle. A longitudinal study by the same researchers confirmed the age-related improvements in anaerobic performances and also reported greater improvements in males than in females, again attributing the changes to qualitative adaptations (Martin, Doré, Twisk, Van Praagh, Hautier, Bedu, 2004). The percentage distribution of type II fibres (greater force producing fibres with greater glycolytic than aerobic capacity) is lower in children than adults and increases during adolescence (Fournier, Ricci, Taylor, Ferguson, Montpetit, & Chaitman, 1982). Increased percentage of type II fibres as well as improved motor unit recruitment and motor coordination with increasing age may therefore, improve anaerobic performances (Van Praagh, 2000).

Quantitative changes that occur during growth and maturation, including increased muscle size and cross sectional area, also contribute to improved anaerobic capacity. In two studies lean body mass explained approximately 90% of the variance in maximal anaerobic power (Doré, Diallo, Franca, Bedu, & Van Praagh, 2000; Mercier, Mercier, Granier, Le Gallais, & Prefaut, 1992). Thigh muscle volume was the strongest explanatory variable for peak power during cycling in 12 -14 year boys and girls (Santos, Armstrong, De Ste Croix, Sharpe, & Welsman, 2003). Thus, during adolescence both boys and girls but especially boys, will experience substantial improvements in anaerobic capacity related to physical growth in size as well as age-related qualitative improvements in neuromuscular function.

In addition to growth-related increases in anaerobic capacity, anaerobic performances during childhood and adolescence may improve with training. In preadolescent boys, sprint training improved mean power (10%) and peak power (14.2%) measured during Wingate anaerobic tests (Rotstein, Dotan, Bar-or, & Tenenbaum, 1986). Thirteen weeks of interval and continuous aerobic run training improved maximal cycle peak power by 23% in prepubertal participants (Obert, Mandigout, Vinet, & Courteix, 2001). Maximal-shuttle run velocity has also been shown to improve following aerobic training in prepubertal children (Baquet, Berthoin, Dupont, Blondel, Fabre, & Van Praagh, 2002). Few studies have investigated anaerobic trainability during adolescence (Van Praagh & Doré, 2002). In pubertal boys, complex training including a combination of resistance training and plyometrics improved anaerobic power (5.5%) as well as jumping, throwing, sprinting, and dynamic strength (Ingle, Sleap, & Tolfrey, 2006). Sprint training increased PFK activity by 21% in pubertal boys, demonstrating the trainability of anaerobic muscle metabolism during puberty (Fournier et al., 1982). Limited data that exist as well as the trigger point hypothesis (Katch, 1983) coinciding with puberty suggest that anaerobic trainability increases substantially during puberty.

The lower anaerobic capacity of younger athletes may be explained by metabolic factors. Muscle biopsy and ^{31}PNMR has confirmed that adenosine triphosphate (ATP) and phosphocreatine levels are similar in adolescents and adults (Eriksson et al., 1971; Eriksson & Saltin, 1974; Zanconato, Buchthal, Barstow, & Cooper, 1993). Anaerobic power in particular relies on available ATP and phosphocreatine (PCr) stores to rapidly facilitate production of external work. Peak power differences between children, adolescents, and adults are therefore, not explained by availability of high energy phosphates at rest. The ratio of phosphate (Pi) to PCr, a measure of muscle metabolism which increases with increasing exercise demands, has been shown to be 27% lower in children than in adults post-exercise (Cooper & Barstow, 1996). While not all studies have supported this finding (Petersen, Gaul, Stanton, & Hanstock, 1999), differences in muscle metabolism rates, especially a lower glycolytic capacity partially account for the lower anaerobic capacity of children and adolescents (Boisseau & Delamarche, 2000; Kuno et al., 1995; Taylor, Kemp, Thompson, & Radda, 1997).

As previously discussed muscle and liver glycogen may be lower in children and adolescents. Compared with adults, glycogen may be as much as 60% lower (Eriksson et al., 1971; Eriksson et al., 1973). Furthermore, lower glycolytic enzyme concentrations including phosphofructokinase (PFK), lactate dehydrogenase, aldose, and pyruvate kinase have been reported in children compared with adults (Berg, Kim, & Keul, 1986; Eriksson et al., 1973, Kaczor, Ziolkowski, Popinigis, & Tarnopolsky, 2005). Therefore, while muscle ATP and PCr content do not differ with age, it is clear that children and adolescents have impaired high energy phosphate kinetics during exercise. In adults, training improves anaerobic metabolism by increasing muscle ATP, PCr, and glycogen content as well as increasing enzyme activity (Nevill, Boobis, Brooks, & Williams, 1989). Training during adolescence probably results is these same adaptations (Eriksson, 1980; Fournier et al., 1982) although more research is need to verify this.

While anaerobic performances are lower in children and adolescents, they appear to experience less fatigue and recover from high intensity efforts quicker than adults. Decline in muscle power during 4 × 30 second and 2 × 60 second maximal knee extensions-flexions has been shown to be smaller in boys compared to adolescents and adults (Zafeiridis, Dalamitros, Dipla, Manou, Galanis, & Kellis, 2005). During repeated 30 second Wingate tests, prepubertal boys were able to replicate 100% of their performance after 2 minute recoveries compared with adults who required ten minutes (Hebestreit, Mimura, & Bar-Or, 1993). Similarly, recent research found percentage decline in power during 30 second Wingate tests was lower in boys than in adult men (Beneke, Hütler, Jung, & Leithäuser, 2005). The rate and magnitude of recovery from high-intensity efforts is influenced by maturational status. With increasing age, the percentage decline in peak power during repeated sprints has been shown to increase (Ratel, Bedu, Hennegrave, Doré, & Duché, 2002). Younger athletes may therefore, require shorter rest periods during training than adults (Bar-Or, 1995). Many mechanisms have been proposed to explain the recovery differences between adults and children and adolescents including quantitative and qualitative muscles characteristics, and neurological factors such as motor unit recruitment patterns (Ratel et al., 2006). Recently, ^{31}PNMR was used to demonstrate greater muscle oxidative capacity in children than in adults (Ratel et al., 2008). Recovery of PCr relies exclusively on oxidative processes (Bogdanis, Nevill, Boobis, & Lakomy, 1996). A greater oxidative capacity will therefore, contribute to improved recovery and repeated effort ability. Children and adolescents’ lower power production compared with adults is however, postulated to be the biggest contributor to their improved recovery (Falk & Dotan, 2006).

The size and fibre distribution of skeletal muscle, muscle recruitment patterns, biochemical, and enzymatic characteristics influence the ability to perform high intensity exercise. In addition to growth-related improvements in these factors, adolescents appear capable of adapting to anaerobic training thereby improving their capacity to perform high intensity exercise. During training, adolescents may require shorter recovery periods than typically prescribed to adults. Male adolescents in particular seem well apt for high-intensity training and performances.

2.1.3.3 Strength

After several decades of controversy regarding strength training during childhood and adolescence, it is now widely accepted that correctly supervised, developmentally appropriate resistance training programs can safely and effectively improve strength and muscular endurance in young populations (American College of Sports Medicine, 2006; Behm, Faigenbaum, Falk, & Klentrou, 2008; Malina, 2006; Bernhardt, Gomez, Johnson, Martin, Rowland, Small, LeBlanc, Malina, Krein, Young, Reed, Anderson, Griesemer, & Bar-Or, 2001; Stratton, Jones, Fox, Tolfrey, Harris, Maffulli, Lee, & Frostick, 2004). The potential for injury however, remains a major concern for children and adolescents engaged in poorly designed and, or, unsupervised resistance training (Naughton et al., 2000). Improvements in strength observed in association with resistance training also appear to occur as a result of differing physiological adaptations in younger people compared with adults.

Force production (strength) is governed by similar muscle, neurological, motivational, coordination, hormonal and metabolic factors to those employed during anaerobic performances. Thus, as occurs with anaerobic capacity, growth and development-related muscle morphological, neurological, and hormonal adaptations that occur during puberty result in increased strength (Tanner, 1978).

In boys, strength increases linearly until the onset of puberty, after which accelerated growth and hormonal changes coincide with a strength spurt that occurs approximately one year after PHV (De Ste Croix, 2007). In boys in particular, considerable increases in absolute, as well as relative strength are observed during growth and development. Between the ages of 9 and 21 years, absolute knee extensor and flexor strength in males has been shown to increase by 314 and 285%, respectively (De Ste Croix, Armstrong, & Welsman, 1999). Muscle strength per unit of body mass increases in boys from 9 until about 18 years of age (Kanehisa, Ikegawa, & Tsunoda, 1995).

The exact mechanisms accounting for increases in strength during growth and development remain unknown. Certainly, increased muscle size, or more specifically, increased physiological cross sectional area (pCSA) accounts for a large portion of strength gains (Deighan, Armstrong, & De Ste Croix, 2002; Wood, Dixon, Grant, & Armstrong, 2004). However, muscle hypertrophy is not always necessary for increases in strength. In highly trained adult weightlifters, strength improved over two years of training in the absence of any changes in muscle size (Häkkinen, Pakarinen, Alen, Kauhanen, & Komi, 1988a). During adolescence, strength may increase disproportionately to growth and development-induced muscle hypertrophy. More optimal muscle angle of pennation, improved motor unit recruitment, motor coordination, biochemical, and hormonal adaptations may contribute to observing increases in muscle strength disproportional to size (Kraemer & Spiering, 2006).

Resistance training studies among early and midpubescent participants have consistently demonstrated good strength trainability (Christou, Smilios, Sotiropoulos, Volaklis, Pilianidis, & Tokmakidis, 2006; Faigenbaum, Westcott, Michelli, Outerbridge, Long, LaRosa-Loud, & Zaichkowski, 1996; Lillegard, Brown, Wilson, Hendersen, & Lewis, 1997; Pfeiffer & Francis, 1986; Sailors & Berg, 1987). Evidence of hypertrophy is however, equivocal (Malina, 2006). A meta-analysis of 28 resistance training studies among children and adolescents reported a mean effect size (ES) of 0.75 (±0.57) for improvements in strength. Effect sizes in this study were similar for younger (children) and older groups (adolescents) (Payne, Morrow, Johnson, & Dalton, 1997). In children under the age of 13 years, increases in strength between 13 and 30% in response to resistance training have been reported (Falk & Tenenbaum, 1996). Older boys and adolescents often demonstrate much greater training-induced improvements in absolute strength compared with younger boys (Malina, 2006) and strength gains of similar magnitude between adolescent boys and young men have also been reported (Sailors & Berg 1987).

In adults, neurological adaptations to resistance training account for initial improvements in strength (Moritani & Devries, 1979). Subsequent increases in strength occur principally as a result of muscle hypertrophy (Philips, 2000). It is not currently clear if adolescents consistently experience strength training-induced muscle hypertrophy. Some studies have reported minimal gains in muscle hypertrophy (Lillegard et al., 1997), while others have demonstrated significant increases in muscle cross sectional area for adolescents (Vrijens, 1978) and even children (Fukunaga, Funato, & Ikegawa, 1992). Literature regarding muscle hypertrophy during puberty is clouded by a lack of studies and the tendency to group adolescents of vastly different pubertal stages together. More research is clearly needed to investigate muscle hypertrophy responses at specific stages of maturation during puberty. In light of current knowledge, the absence of substantial increases in muscle size during puberty suggests adolescents increase strength primarily by neurological adaptations. Improved motor unit recruitment and activation of muscles during specific tasks is likely to contribute to increased strength, at least initially (Folland & Williams, 2007).

Many factors including muscle cross-sectional area and motor unit recruitment patterns determine muscle strength. Muscle strength increases during growth and maturation and boys are advantaged by experiencing a strength spurt early on in puberty. While it is still unclear whether adolescent muscle hypertrophies in response to resistance training, there is little doubt that they will experience considerable increases in strength over and above the increases arising from normal growth and maturation. Adolescents are therefore, capable of deriving strength benefits from resistance training that appear to primarily occur as a result of neurological adaptations.

2.1.4 Adolescents and injury

Sporting injuries in young athletes are a major concern. In young athletes in particular, the consequences of injuries are not just limited to the short-term impact on individuals. Longer-term deleterious outcomes could include a reduction in, or a complete cessation of participation in sport and physical activity, disruption to normal growth and development, physical disability or dysfunction, premature onset of degenerative diseases, lost opportunities to succeed in sporting pursuits, as well as possible negative psychological manifestations. While the prevalence of such outcomes among injured youth continues to prove exceedingly difficult to quantify, reducing injuries among young athletes remains a major priority.

Adolescents may be at greater risk of injury than children. Among children and adolescents injury rates increase with age across a wide variety of sports with adolescents aged more than 13 years at greater risk of injury than children (Bijur, Trumble, Harel, Overpeck, Jones, & Scheidt, 1995; Goldberg, Rosenthal, Roberston, & Nicholas, 1988; McMahon, Nolan, Bennett, & Carlin, 1993; Yde & Nielsen, 1990). It is not currently clear whether injury severity also increases with increasing age, although anecdotally this appears to be the case for some types of injuries. In addition to being high relative to younger participants, the incidence of injuries among adolescent athletes is considered both high and concerning (Emery, 2003). Growing tissues, accelerated growth and development, behavioural changes, and changes in participation patterns appear to be some of the major contributors to the increased injury risk during adolescence.

Sporting injuries can be the result of either modifiable or non-modifiable risk factors (Meeuwisse, 1991) that contribute to both acute and overuse type injuries.

Rugby is a high intensity, collision sport involving many exposures to potential injurious situations. Furthermore, participation in intensive training and competition in any sport also increases player’s risks of sustaining injuries, particularly overuse type injuries. Consequently, it is conceivable that many players involved in adolescent rugby sustain acute and overuse injuries, many of which are preventable. Since adolescence represents such a unique period of growth and development, the nature of acute and overuse injuries sustained during growth and maturation are often different from those occurring during adulthood. Therefore, in addition to a brief review of injuries in the sport of rugby union, this section will limit discussions to acute and overuse modifiable types of injuries especially prevalent among adolescent athletes.

2.1.4.1 Incidence and nature of injuries in rugby union

Injury definitions and methodological approaches used in injury surveillance studies are highly varied. Consequently, interpreting studies to describe the incidence of injuries in rugby union and to make comparisons to other sports is difficult (Fuller, Molloy, Bagate, Bahr, Brooks, Donson, Kemp, McCrory, McIntosh, Meeuwisse, Quarrie, Raftery, & Wiley, 2007a). Broadly speaking, researchers typically define injuries as any pain or disability sustained during participation in sport. Whether such pain or disability is recorded as an injury however, depends on the specific definitions selected. In some studies all injuries sustained during competition and training are included when determining injury incidence. In others, only injuries severe enough to require medical attention or that result in lost time are recorded. An additional limitation to interpreting injury surveillance studies is that many studies report injuries relative to participant numbers and fail to adjust data relative to exposure (Emery, 2003). Despite these limitations, rugby union is associated with one of the highest rates of injuries among popular professional team sports (Bathgate, Best, Craig, & Jamieson, 2002; Brooks, Fuller, Kemp, & Reddin, 2005a; Brooks, Fuller, Kemp, & Reddin, 2005b; Fuller, Laborde, Leather, & Molloy, 2008). Injury rates in rugby union at the adolescent level also appear high relative to other team sports (Adickes & Stewart, 2004; Grimmer & Williams, 2003; Junge, Cheung, & Dvorak, 2004; McManus & Cross, 2004).

When adjusted for exposure, overall (training and games combined) injury rates among adolescent rugby players range from 3.4 to 27.5 per 1000 playing hours (Collins, Micheli, Yard, & Comstock, 2008; Davidson, 1987; Durie & Munroe, 2000; Garraway & Macleod, 1995; Junge et al., 2004; McManus & Cross, 2004; Pringle, McNair, & Stanley, 1998; Roux, Goedeke, Visser, Van Zyl, & Noakes, 1987; Sparks, 1981; Sparks, 1985). Comparative injury data for junior Australian Football players (7.8 per 1000 playing hours) (Orchard, Wood, Seward, & Broad, 1998), soccer players (21 per 1000 playing hours), and baseball players (17 per 1000 playing hours) (Radelet, Lephart, Rubinstein, & Myers, 2002) supports that injury rates among rugby union players are relatively high. When rugby games and training are considered separately, the incidence of injuries during games is considerably higher (Durie & Munroe, 2000; Junge et al., 2004; Lee & Garraway, 1996; Roux et al., 1987; Sparks, 1985). Recently, game injuries were reported to be 129.8 injuries / 1000 game hours among high school players when all physical complaints were classified as injuries (Junge et al., 2004). Lower injury rates per 1000 game hours of 65.8 (Durie & Monroe, 2000) and 62 (Bird, Waller, Marshall, Alsop, Chalmers, & Gerrard, 1998) have been reported in other studies where only more severe events that precluded continued participation in a game met the criteria for an injury.

Injury rates in rugby appear to increase with increasing player age (Davidson, 1987; Lee & Garraway, 1996, Roux et al., 1987) and level of play (Brooks et al., 2005a; Lee & Garraway, 1996, Lee, Garraway, & Arneil, 2001). However, incidence rates of 69.8 injuries / 1000 game hours during the 2007 Rugby World Cup and 91 injuries / 1000 game hours in professional English club players approximate the rates reported in some studies of adolescent level rugby. Therefore, it not clear whether adolescents sustain fewer injuries than older, more elite players. A recent consensus statement on definitions and data collection procedures for studying injuries in rugby should assist in resolving this question (Fuller et al., 2007a). However, until standard definitions and protocols become widely accepted, the incidence of injuries in rugby, particularly with respect to age and level of play will continue to be difficult to establish.

2.1.4.2 Acute injuries and factors contributing to risk

In agreement with reports from other contact sports, acute injuries in rugby most commonly occur during contact phases. The tackle in particular has been reported to account for a majority of injuries (24-50%), followed by rucks (6-17%), mauls (12-16%), collisions (8-9%), and scrums (2-8%) (Bathgate et al., 2002; Bird et al., 1998, Bottini, Poggi, Luzuriaga, & Secin, 2000; Fuller, Brooks, Cancea, Hall, & Kemp, 2007b; Lee & Garraway, 1996; Quarrie & Hopkins, 2008). Since the frequency of contact is likely to impact the rate of injury, the probability of a contact event resulting in injury is most accurately determined by adjusting for exposure. The contention that tackles occur more frequently than other contact events is likely to contribute to the much greater numbers of injuries observed during this phase of play. Relative to exposure, collisions have been reported to be 70% more likely and scrums 60% more likely to result in an injury than a tackle (Fuller et al., 2007b). Nevertheless, since players are involved in many tackles during a game, tackles, scrums and rucks are clearly more injurious than other contact events and therefore, contribute most to acute injuries during rugby.

The most common site of acute injury in rugby depends on how sites are grouped and whether or not game and training injuries are analysed separately. In one review, the greatest proportion of match injuries among adolescent players was reported to occur to the head, face and neck followed by a relatively even distribution between upper and lower extremities (McIntosh, 2005). In a study of elite junior players, lower limbs followed by head and neck, and then shoulder were the most common sites (McManus & Cross, 2004). The distribution of match injuries by site among adult players appears similar although large variations in reported injury patterns exist (Bird et al., 1998; Kerr, Curtis, Michelli, Kocher, Zurakowski, Kemp, & Brooks, 2008). During training, where typically fewer contact events occur, head, face, and neck injuries represent a smaller proportion of injuries by site than lower limb injuries (Bird et al., 1998, Brooks et al., 2005a, Brooks et al., 2005b). Strains and sprains are consistently reported to be the most common types of injuries sustained by players across all ages and levels of play, while lacerations, fractures, dislocations, contusions, and concussions are not uncommon (Bird et al., 1998; Kerr et al., 2008; McIntosh, 2005).

Since acute injuries most frequently occur during contact, factors related to growth and maturation may contribute to the apparent increase in impact injuries with increasing age and level of play. In contact sports such as rugby, injury risk may increase by virtue of the increasing size and strength of adolescents and the resultant increase in momentum during running, stopping, pivoting, and colliding (Adirim & Cheng, 2003; Lee & Garraway, 1996). With such wide variations in growth and strength spurts during adolescence, there is also the possibility that a size and strength mismatch of same chronological age players during competition may further increase risk of injury among some players (Malina, Pena Reyes, Eisenmann, Horta, Rodrigues, & Miller, 2000). Considerable improvements in motor as well as perceptual-cognitive skill proficiencies occur during growth and maturation (Vaeyens, Lenoir, Williams, & Philippaerts, 2008). These improvements are however, likely to be more variable during adolescence than during adulthood. Therefore, differences in players' motor skill ability during game activities, especially tackling, rucking, and mauling, may further contribute to injury risk as lower skilled players engage in these activities against higher skilled players (McIntosh, 2005). The role of perceptual-cognitive skill differences in injury risk is unclear. However, the superior ability of some players to make decisions quickly, think more abstractly, and predict future outcomes of play may increase risk of injury through mechanisms yet to be readily quantified. Changing player behaviour and participation patterns may also contribute to greater injury risk during adolescence. During school, participation in sport is often compulsory. As players' age and level of play increases, compulsory participation diminishes. It is possible that adolescents who continue to participate in rugby are more committed, physically larger and stronger and play with greater intensity (Lee & Garraway, 1996). Furthermore, competitiveness and sporting aggression increases with age (Price, Hawkins, Hulse, & Hodson, 2004) and adolescents appear to be greater risk takers (Backous, Freidl, Smith, Parr, & Carpine, 1988). Therefore, larger, stronger players, with a greater competitive drive and aggression who engage in more risky behaviour during competition are conceivably likely to sustain more injuries than their less advanced peers. Factors explaining the incidence of acute injuries sustained during rugby union are multifactorial and many more factors than those described here exist. However, as it relates to adolescence, the intrinsic and extrinsic changes related to growth and maturation as well as participation patterns appear to contribute to the higher incidence of injury in adolescent players compared with younger players.

2.1.4.3 Overuse injuries and factors contributing to risk

Growing bone, muscle, cartilage, and ligament is more vulnerable to injury than these tissues in adults (Adirim & Cheng, 2003). This increased vulnerability may therefore, contribute to an increased incidence, and possibly severity, of both acute and overuse type injuries during adolescence. Typically, overuse injuries arise from chronic, repetitive loading for which recovery time is insufficient to restore a normal state (DiFiori, 1999; Hogan & Gross, 2003). During adolescence, repetitive microtraumas arising from stressors associated with participation in sport that may be tolerated by adults often result in injury in growing tissue. Additionally, during accelerated periods of growth at which the development of some systems or tissues lag behind others, the risks of certain types of overuse injuries are further increased among young athletes (Caine, DiFiori, & Maffuli, 2006). Overuse injuries, once rare among adolescent populations, are a growing concern with relatively large numbers of athletes becoming injured (Adirim & Cheng, 2003; Brenner, 2007, Caine et al., 2006; Louw, Manilall, & Grimmer, 2008; Micheli & Klein, 1991). Many overuse injuries among adolescents may be preventable (Smith, Andrish, & Micheli, 1993).

Determining the incidence of overuse injuries in rugby is difficult. Studies inclusive only of injuries resulting in time lost may ignore reports of many adolescents who play with repetitive and growth-related injuries such as Osgood Schlatter and Sever’s Disease. Overuse injuries are often either not described in epidemiological studies or are collectively included as a general category of injuries defined as ‘training injuries’. Consequently, information regarding the exact nature, consequences, incidence, and contributing mechanisms is limited since ‘training injuries’ include both overuse and acute injuries. Additionally, under reporting of overuse injuries by players as well as an inability to always clearly delineate overuse injuries, recurrent injuries, and the extent to which the presence of an overuse injury may have contributed to an acute injury further complicates attempts to quantify overuse injuries. From existing data, it is clear that overuse injuries in rugby are less common than acute injuries. In a study of adolescent soccer and rugby players, 15% of all injuries were attributed to overuse, rugby players sustaining more of these injuries than the soccer players (Junge et al., 2004). In other studies of adolescent rugby players, considerably more acute injuries than overuse injuries were reported (Le Gall, Carling, & Reilly, 2007; Volpi, Pozzoni, & Galli, 2003). However, the relatively high incidence of idiopathic tendinopathies and osteochrondal disorders among players was noted (Le Gall et al., 2007; Volpi et al., 2003). Therefore, while the incidence of acute injuries is higher, overuse injuries remain a concern.

Four categories of overuse injuries exist, including stress fractures, tendinitis, and apophysitis of tendon insertions, bursitis, and joint disorders (Micheli, 1983). In stress fractures, cortical bone fails under repetitive loading when normal bone remodelling involving osteoblast stimulation (bone formation) and osteoclastic activity (bone absorption) becomes unfavourably altered (Hogan & Gross, 2003). Stress fractures may be less common in adolescents than in adults because bone regeneration potential is higher during growth (Manjón Llorente, Fernández-

Espuelas, González López, Ruiz-Escharri, & Baldellou Vázquez, 2004). However, in spite of a greater remodelling potential in the more elastic, cartilaginous immature skeleton, stress fractures are still a concern during adolescence (Niemeyer, Weinberg, Schmitt, Kreuz, Ewerbeck, &nKasten, 2005) and the risk of sustaining a stress fracture has been shown to be inversely proportional age. Among 783 military recruits, those younger than 20 years of age had a 26% incidence of stress fractures compared with 2.9% for recruits between the ages of 21 and 26 years (Milgrom, Finestone, Schlamkovitch, Rand, Lev, Simkin, & Weiner, 1994).

Tendinitis (inflammation of tendons) and bursitis (inflammation of bursa) are less common during adolescence while physeal injuries appear to be particularly prevalent (Caine et al., 2006; Micheli & Fehlandt, 1992; Micheli & Klein, 1991). Physeal injuries result from mechanical loads exceeding bone and cartilage tolerance at regions of growth and therefore, occur almost exclusively during childhood and adolescence. These regions of growth include the physis and epiphysis, as well as apophyses at which tendons attach and also stimulate bone remodelling. Cartilage and bone at these sites of growth, temporarily weakened by the process of growth, are highly susceptible to injury (Caine et al., 2006; Maffulli, 1990). Ligaments are also stronger than bone, making repetitive microtraumas more likely to result in partial avulsion fractures than ligament sprains. This susceptibility is particularly evident during periods of accelerated growth such as occurs during the adolescent growth spurt (Baily, Wedge, McCulloch, Martin, & Bernhardson, 1989; Caine et al., 2006; Maffulli, 1990).

Muscle-tendon tightness that may accompany the adolescent growth spurt could also contribute to the greater risk of injury to bone, articular surfaces, and attachment sites in these regions of growth (Connolly, Connolly, & Jaramillo, 2001; Micheli & Fehlandt, 1992). Muscle-tendon tightness as an injury risk is not supported by all, and increased muscle-tendon tightness resulting from growth is yet to be proven (Feldman, Shrier, Rossignol, & Abenhaim, 1999).

Apophysitis appears to be the most common of these growth-related musculoskeletal disorders, with the knee (Osgood-Schlatter disease) and foot (Sever's disease) the most afflicted sites. Osgood-Schlatter disease is a traction apophysitis of the tibial tuberosity at the attachment of the patellar tendon. Sever's disease is an equivalent disorder at the Achilles tendon attachment on the calcaneus (Adirim & Cheng, 2003; Hogan & Gross, 2003). Joint disorders are also not uncommon among adolescent athletes. Repetitive loading during growth is associated with injury to subchondral bone and articular surfaces by both fracturing and comprising vascular flow (Ryu & Fan, 1998). A common form of this type of injury is osteochondritis dissecans (Micheli & Klein, 1991). All these conditions occur in highly physically active children and adolescents and may be exacerbated by an unwillingness to rest for recovery, general energy drain over a prolonged period of time, or external pressures to continue to participate in sport and physical activity.

In addition to potential influences already highlighted, many other factors contribute to risk of overuse injuries in adolescent athletes. Growth is one of the most significant risk factors and any attempts to manage injury rates should account for changing body composition and length. The susceptibility of growing tissue relates to physiological, biomechanical, and timing and tempo differences that occur during adolescent development of the musculoskeletal system (Micheli & Klein, 1991). If combined with inherent anatomical malalignment and training error, including excessive participation loads with inadequate recovery, the risk of overuse injury is further exacerbated. Early sport specialisation may also contribute to a greater incidence of overuse injuries, although empirical evidence for this notion is lacking.

2.1.5 Section summary

Surprisingly little research involving adolescent athletes exist. Coordinated by the neuroendocrine system, adolescence is a unique stage of growth and development where accelerated physical, physiological, and psychological changes advance the process of maturation. Rapid increases in height and mass, neuroendocrine function, and psychological development make adolescents well suited to training and competition demands of sport. However, there are many considerations that need to be taken into account.

By virtue of physical growth and maturation, functional capacities and consequently athletic performance improve at and during adolescence. In addition, the ‘trigger hypothesis’ suggests that a marked increase in trainability coincides with puberty, particularly in males where hormonal changes become permissive for training adaptations. Despite limited data, endurance performances generally show improvements during the circumpubertal years in response training. Metabolic, haematological and hormonal adaptations to aerobic training result in improved efficiency in oxidative metabolism and support the notion that adolescents are well equipped to adapt to aerobic training. Relative power production during anaerobic efforts is lower in adolescents than in adults. Differences reduce with increasing age particularly in boys where anaerobic performances as well as muscle size and biochemical and neurological adaptations increase substantially during adolescence. Similarly, growth and development-related muscle morphological, neurological, and hormonal adaptations that occur during puberty result in increased strength. Strength in adolescents may increase disproportionately to muscle hypertrophy as result of more optimal muscle angle of pennation, improved motor unit recruitment, motor coordination, biochemical, and hormonal adaptations. Adolescents are capable of deriving strength benefits from resistance training primarily attributed to neurological adaptations. Although significant improvements in functional capacity can be achieved during puberty the magnitude of changes generally appear lower than in adults.

The consequences of injuries among adolescent athletes could include longer-term deleterious outcomes such as complete cessation of participation in sport and physical activity, disruption to normal growth and development, physical disability or dysfunction, premature onset of degenerative diseases, lost opportunities to succeed in sporting pursuits, as well as possible negative psychological manifestations. Growing tissues, accelerated growth and development, behavioural changes, and changes in participation patterns appear to be some of the major contributors to the increased injury risk during adolescence. In addition to the injury risks associated with contact team sports, participation in intensive participation demands, including early specialisation and inadequate recovery increases player's risks of sustaining injuries. Injury rates in rugby union at the adolescent level also appear high relative to other team sports.

2.2 Training and overtraining

2.2.1 Introduction

Achieving optimal adaptations for successful performance requires a careful balance between training stimuli and recovery processes relative to individual athlete's capacities to adapt. Strategically increasing training, resulting in periods of 'overreaching' is often necessary to induce desired training responses. However, if the demands of participation coupled with inadequate recovery become too great, maladaptations can result with undesirable training outcomes. This process is generally referred to as overtraining along a continuum of the training process. In spite of a limited understanding of the mechanisms contributing to overtraining, and varied definitions used in its diagnosis, a prodigious number of markers, signs, and symptoms of overtraining have been identified in the literature.

Since maladaptations to training are likely to manifest in any or several body systems, physiological, psychological, immunological, biochemical, hormonal, and performance markers may all be useful for monitoring the training process and detecting overtraining (Halson & Jeukendrup, 2004; Urhausen & Kindermann, 2002). However, efforts to delineate predictive variables from the large volume of proposed markers, signs, and symptoms within these domains have been impaired. Factors making the prediction of maladaptations difficult include, a lack of scientific evidence (Halson & Jeukendrup, 2004; Meeusen et al., 2006) the indiscriminate relationship between normal intensive training, overreaching, and overtraining (Meeusen et al., 2006; Petibois, Cazorla, Poortmans, & Déléris, 2003; Urhausen & Kindermann, 2002), and the incoherent presentation of markers in individual athletes (Smith & Norris, 2000a; Smith, 2003a). Consequently, inconclusive and inconsistent associations are observed between multiple reported markers and overtraining. This section of the chapter will discuss training processes, present contemporary definitions, and review a number of markers of overtraining (see table 2.1 summary of markers of overtraining) to capture current knowledge of the multi-dimensional and multi-factorial aetiology of adaptive and maladaptive training as it may pertain to the adolescent athlete.

Table 2.1 Summary of markers of overtraining.

Markers of overtraining	Suspected changes in overtraining
Physiological markers	
Biological	
Blood lactate	Decreased max and submax
Creatine kinase	Increased concentrations
Uric acid	Increased concentrations
Ammonia	Decreased concentrations
Immunological	
Leukocytes and subpopulations	Decreased concentrations
Glutamine	Decreased concentrations
Immunoglobulins	Decreased concentrations
Upper respiratory tract infections	Increased incidence
Hormonal	
Testosterone	Decreased concentrations
Cortisol	Increased concentrations
Testosterone / cortisol ratio	Decreased ratio
Pituitary hormones	Decreased concentration
Catecholamines	Decreased, increased at rest
cytokines	Increased concentrations
Nutrition and metabolic alterations	
Muscle and liver glycogen	Decreased reserves
Metabolism (bioenergetics)	Compromised bioenergetics
Cardiovascular	
Heart rate (rest)	Increased
Heart rate (submax)	Decreased
Heart rate (max)	Decreased
Heart rate variability	Increased variability
Psychological markers	
Mood states	Increased negative state
Stress and recovery	
Stress	Increased
Recovery	Decreased
Perceived effort and subjective complaints	Increased
Performance markers	Compromised performance

2.2.2 Training and overtraining processes

A training-induced disturbance to homeostasis followed by opportunities for restoration during recovery triggers an array of adaptations that usually include a 'supercompensation effect' to the threshold of tolerance. Serially exceeding thresholds results in an addition to the previous tolerance of stress, and thus improves performance. A simple model of this training-recovery paradigm defines two distinct processes (1) breakdown, during which an overload stimulus disrupts homeostasis and (2) recovery, during which homeostasis is restored (Bompa, 1996; Fry, Morton, & Keast, 1992a; Viru, 1984). The original premise for strategically applying training and recovery to improve sporting performance was derived from general adaptation syndrome (GAS), a model that described a generic response of any organism to a stressor (Selye, 1950). Three distinct phases were proposed; an alarm reaction (disturbance), a stage of resistance (adaptation), and a stage of exhaustion (maladaptation) if the stressor continues beyond the adaptation capacity (Selye, 1950).

Subsequent attempts to better understand stress and adaptation processes as they relate to improving performance in sport have been operationalised as the fitness-fatigue model (Bannister, 1991). While substantively similar, this model distinguishes differing adaptive responses from differing stressors and proposes two training outcomes that either negatively (fatigue) or positively (fitness) impact performance. Furthermore, the physical stress theory (PST) expands the stress-recovery paradigm by including that specific tissues, each with specific upper and lower thresholds for adaptation respond accordingly to physical stressors (Mueller & Maluf, 2002). Collectively, two important points are evident from all theoretical models of the training process. Stressors (training and competing) are necessary to induce adaptations (supercompensation) and adaptation thresholds can be exceeded (maladaptation).

Therefore, adaptations occur along a continuum of the training process with either insufficient, optimal, or excessive stressors relative to individual adaptation thresholds and available recovery processes. Theoretically, to maximise adaptations, periods of optimal or even excessive training stressors coupled with adequate recovery effectively improve performance. However, in practice, determining an optimal balance is challenging. An accumulation of training (and non-training) stressors with insufficient recovery sometimes can occur resulting in maladaptations referred to as overreaching and overtraining (Halson & Jeukendrup, 2004; Kreider et al., 1998; Meeusen et al., 2006; Urhausen & Kindermann, 2002). Frequently cited definitions include, overreaching as an accumulation of training stressors and, or, non-training stressors that result in short-term decrements in performance with or without the presence of physiological and psychological signs and symptoms of maladaptation in which restoration of performance capacity can be restored within a relatively short period of days to weeks (Kreider et al., 1998). On the other hand, overtraining has been defined as an accumulation of training stressors and, or, non-training stressors that result in long-term decrements in performance with or without the presence of physiological and psychological signs and symptoms of maladaptation in which restoration of performance capacity can be restored within relatively long periods of time ranging between weeks to months (Kreider et al., 1998).

Amidst ongoing contention, authors argue these definitions may not adequately describe the nature of the process or outcome proposed. Specifically, differentiating overreaching and overtraining by the amount of time required for restoration is likely to oversimplify what is a complex interaction between the type of stress and the degree of impairment (Budgett, Newsholme, Lehmann, Sharp, Jones, Jones, Peto, Collins, Nerurkar, & White, 2000b; Halson & Jeukendrup, 2004; Meeusen et al., 2006). Therefore, it may be more accurate to define overtraining as a process of intensified training with possible outcomes including short-term or functional overreaching (transient reduction in performance, followed by improvements), extreme or non-functional overreaching (transient reduction in performance, not followed by improvements), or overtraining syndrome (a non-transient outcome) (Meeusen et al., 2006, see figure 2.1). The advantage of this approach is the greater recognition of outcomes relative to processes. In addition, to better define the aetiology of intensive training, interpreting the processes and outcomes according to these definitions may improve the ability to titrate training and recovery to induce positive and avoid deleterious training outcomes. For example, recognising that intensive training that can result in overreaching is often used as a normal training strategy and is not problematic unless non-functional overreaching (or overtraining syndrome) ensues is important for effective training prescription.

PROCESS	TRAINING (overload)	INTENSIFIED TRAINING		
OUTCOME	ACUTE FATIGUE	FUNCTIONAL OR (short-term OR)	NON-FUNCTIONAL OVERREACHING (extreme OR)	OVERTRAINING SYNDROME (OTS)
RECOVERY	Day(s)	Days-weeks	Weeks-months	Months-...
PERFORMANCE	INCREASE	Temporary performance decrement (e.g. training camp)	STAGNATION DECREASE	DECREASE

Figure 2.1 Possible presentation of the different stages of training, OR, and OTS, (reproduced from Meeusen et al., 2006).

The consequences of overtraining and overtraining syndrome are poorly understood. At times, intensive training responses may coincide, or even interact, with pre-existing symptoms of athlete burnout, thus making burnout an additional extreme outcome on the training continuum. Athlete burnout has been classically defined as a psychological, emotional, and at times physical withdrawal from a formerly pursued and enjoyable activity due to chronic stress or dissatisfaction (Smith, 1986). More recently, burnout has been defined as a psychological syndrome of emotional / physical exhaustion, reduced sense of accomplishment, and sport devaluation, associated with intense demands of participation in sport (Raedeke & Smith, 2001). While grounded in psychological theory, therefore, emphasising psychological causes and effects, it is plausible considerable cross-over exists between burnout and overtraining. However, potential interactions are not well understood. Multiple definitions for training processes and deleterious training outcomes exist in the literature. For the purposes of this thesis any accumulation of excessive, intensive participation and non-participation stressors coupled with inadequate or inappropriate recovery is considered to increase the risk of deleterious outcomes that may be severe enough to constitute chronic maladaptation.

2.2.3 Incidence of overtraining

Difficulty defining and diagnosing overtraining has contributed to a lack of evidence regarding its incidence. Relatively few studies have attempted to quantify the incidence of overtraining, and since reported rates in these studies were determined using varied definitions of overtraining, the incidence remains unclear. Nevertheless, the incidence of overtraining or perhaps more accurate given the disparity in definitions used, evidence of maladaptation among athletes has been suggested to be relatively high (Halson & Jeukendrup, 2004). Studies among swimmers using performance (Hooper, Mackinnon, & Hanrahan, 1997) and psychological (Morgan, Brown, Raglin, O'Conner, & Ellickson, 1987; O'Connor, Morgan, Raglin, Barksdale, & Kalin, 1989; Raglin & Morgan, 1994; Raglin, Sawamura, Alexiou, Hassmen, & Kentta, 2000) criteria reported incidence rates between 5 and 35%. In a study of British National and Olympic teams, using subjective ratings of fatigue and underperformance, an incidence rate of 15% was reported (Koutedakis & Sharp, 1998). In team sports, there is a paucity of evidence regarding the incidence of overtraining. In young Swedish athletes participating in a variety of team sports, 30% of athletes reported being ‘stale’ (synonymous with overtrained), determined using psychological markers of training distress. In professional soccer, signs of overtraining were reported to be present in 30-50% of players at some point within the season (Naessens, Chandler, Kibler, & Driessens, 2000). Studies assessing burnout among adolescent team and individual sport athletes report incidence rates for elevated burnout scores between 1 and 9% (Gustafsson, Kentta, Hassmen, & Lundqvist, 2007). In longitudinal studies of elite rugby union players, small numbers of athletes were considered ‘at risk’ for burnout by self reporting high burnout scores (Cresswell & Eklund, 2006; Hodge, Lonsdale, & Ng, 2008).

2.2.4 Adolescents and overtraining

Adolescent athletes are at risk of experiencing maladaptation in response to the participation demands of sport. Many of the same risk factors for overtraining elite adult athletes also apply to adolescent athletes. However, additional risks unique to the adolescent athlete also exist. Perhaps driven by the professionalisation of most sports (De Knop, Engström, & Skirstad, 1996) and early opportunities to ‘specialise’ there is an increased focus on identifying and developing talent among young athletes to maximise performance achievements. This trend has impacted training approaches and sporting pathways in ways that have both improved scientific training methodologies and concomitantly increased the risk of young athletes overtraining. Elite athlete training approaches are often ‘superimposed’ onto adolescent athletes (Smith, 2003b), exposing them to participation loads (volume and intensity of training and competition) that may well exceed adaptation thresholds. Furthermore, the nature of participation in sport is different for the adolescent and adult athlete. Adolescents often participate in more than one sport and sometimes also for more than one team within the same sport, adding to the demands placed on them (Brenner, 2007; Finch, Donohue, Garnham, & Seward, 2002). Contemporary sport development pathways, as well as theories of development of expertise in sport, also create additional training risk factors not problematic among the professional ranks of adult athletes.

In addition to the effects of various principles of training already outlined, adolescent participation in sport has been shaped by at least two prominent, but conflicting theories of development of expertise (1) deliberate practice and an early specialisation pathway (Ericsson et al., 1993) and (2) deliberate play and a developmental model of sport participation (Baker et al., 2003; Côté, 1999; Côté, Baker, & Abernethy, 2007). Deliberate practice is defined as any training activity that is undertaken with the specific purpose of increasing performance, is frequently not enjoyable, requires effort and attention, and is relevant to promoting specific skill development (Ericsson et al., 1993). Furthermore, deliberate practice theory proposes a notion of a monotonic (linear) relationship between time spent in deliberate practice and level of performance achieved. Evidence that elite musicians can be differentiated by the number of deliberate practice hours accumulated was used to support that the amount of deliberate practice may be the causal factor in the development of expertise. Deliberate practice theory has subsequently been applied to sport, with some evidence that such an approach may well be necessary for attaining a high level of performance (Helsen et al., 1998; Hodges & Starkes, 1996). Deliberate practice theory confirms an already long-established convention in training for sport of ‘more is better’, and also proposes increasing deliberate practice at younger ages when peak performance is the goal. Unsurprisingly, talent identification programs based on the deliberate practice model have attempted to improve success by incorporating highly structured and voluminous training strategies.

In contrast, other pathways have recognised the possibilities of deliberate play strategies as a fundamental part of the developmental process. Deliberate play is characterised by early sporting activities that are intrinsically motivating and rewarding, and are predominantly undertaken for enjoyment (Côté et al., 2007). Most research has failed to establish the efficacy of detecting talent at a very young age, particularly in more complex team sports (Vaeyens et al., 2008), therefore, questioning the value of implementing deliberate practice strategies during the early stages of sport participation. According to the developmental model of sports participation (DMSP figure 2.2) (Côté et al., 2007), the three age-appropriate phases of participation along the sporting pathway to development of expertise are; the sampling years (5-12 years), the specialisation years (13-15 years), and the investment years (16+ years). Following the principles of each phase may be associated with more desirable outcomes than an early specialisation approach (Côté, 1999; Côté et al., 2007). The DMSP still values the role of deliberate practice, but suggests this should commence in the specialisation years and become the predominant form of training activity during the investment years. It also emphasises the importance of less formal, less structured activities, especially for younger athletes.

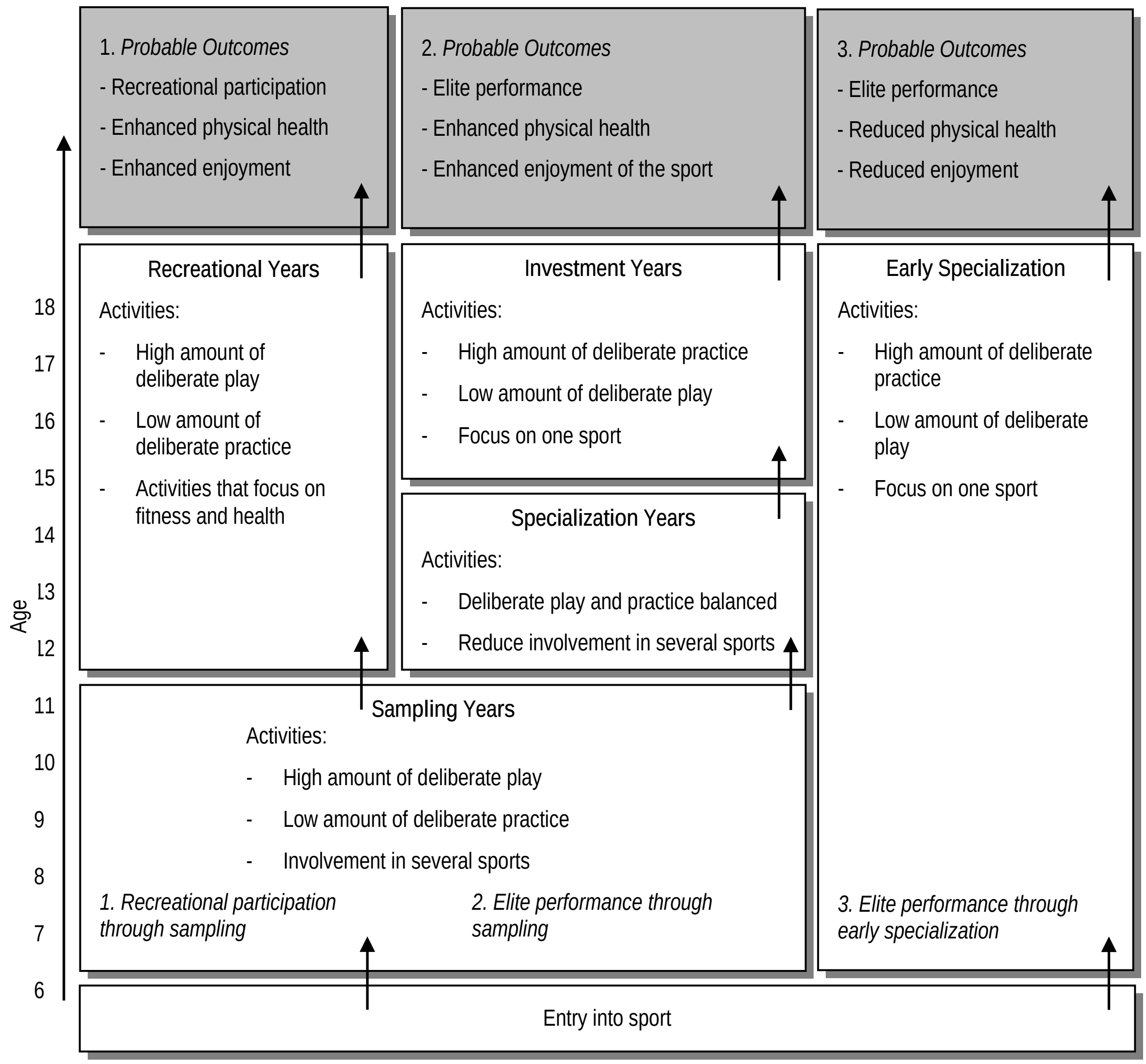

Figure 2.2 Developmental model of sport participation (reproduced from Côté et al., 2007).

In practice, both models have guided current approaches used globally in youth sports. Therefore, by the time young athletes reach adolescence, some may have already accumulated many hours of deliberate practice, while others may be transitioning from sampling, to specialisation years with an increase in the amount of deliberate practice undertaken. Both approaches may increase the risk of adolescents experiencing deleterious training outcomes either through years of accumulated, or sudden unaccustomed increases in deliberate practice. While the most appropriate sporting developmental models appear to be influenced by the performance requirements of specific sports, increasing evidence favours a long-term developmental model incorporating aspects of DMSP as well as a greater focus on future rather than short-term performance goals (Côté et al., 2007; Martindale, Collins, & Daubney, 2005; Vaeyens et al., 2008). As it relates to overtraining among adolescence, it should be clear which approach poses the least risk and also that all participation pathways can result in negative outcomes for individual athletes when not appropriately prescribed or managed.

2.2.5 Physiological markers of overtraining

2.2.5.1 Biological

Haematological and biochemical markers become measurably altered in response to exercise, but particularly during intense exercise. A considerable number of studies have therefore, attempted to monitor biological perturbations as a means of detecting overtraining. For example, lowered blood lactate levels during both submaximal and maximal work efforts have been found in some athletes suspected of overtraining (Callister, Callister, Fleck, & Dudley, 1990; Fry, Morton, Garcia-Webb, Crawford, & Keast, 1992b; Gabriel, Urhausen, Valet, Heidelbach, & Kindermann, 1998; Halson & Jeukendrup, 2004; Jeukendrup, Hesselink, Snyder, Kuipers, & Keizer, 1992; Lehmann, Mann, Gastmann, Keul, Vetter, Steinacker, & Häussinger, 1996; Snyder, Kuipers, Cheng, Servais, & Fransen, 1995; Urhausen, Gabriel, Weiler, & Kindermann, 1998a). An acute shift to the right in lactate curves was shown in cyclists participating in an intensive training period (Jeukendrup & Hesselink, 1994). Since this observation contrasts with elevated lactate scores normally observed during intensive exercise (Gleeson, Blannin, Walsh, Field, & Pritchard, 1998), alterations in blood lactate scores were proposed as a means of early detection of overtraining. More recently, experimentally inducing non-functional overreaching (overtraining) did not result in reduced blood lactates (Coutts, Reaburn, Piva, & Rowsell, 2007a). Altered blood lactate concentrations should be interpreted cautiously since levels are easily affected by confounders, particularly muscle and liver glycogen, environmental extremes, and resting status (Meeusen et al., 2006).

Other biological markers investigated in overtraining research include; concentrations of creatine kinase (Hartmann & Mester, 2000; Hortobagyi & Denahan, 1989; Karvonen, 1992; Kirwan, Costill, Flynn, Mitchell, Fink, Neufer, & Houmard, 1988; Lehmann, Dickhuth, Gendrisch, Lazar, Thum, Kaminski, Aramendi, Peterke, Wielande, & Keul, 1991), urea (Hartmann & Mester, 2000), uric acid (Kirwan, Costill, Houmard, Mitchell, Flynn, & Fink, 1990), and ammonia (Lehmann, Foster, Dickhuth, & Gastmann, 1998). Creatine kinase reflects acute muscular stress in response to intense training (Halson, Lancaster, Jeukendrup, & Gleeson, 2003; Hoffmann, Kang, Ratamess, & Faigenbaum, 2005). However, the association of creatine kinase with chronic accumulative loading and overtraining is uncertain. Further, for some athletes classified as 'non-responders' creatine kinase levels vary very little, despite intensive training (Gleeson, 2002; Urhausen & Kindermann, 2002). Increases in urea and uric acid reflect increases in protein catabolism, an expected response to intensive training. Measurable increases in the level of these nitrogenous by-products occur in response to intense training (Hartmann & Mester, 2000). However, their usefulness as markers of overtraining has not been established (Gleeson, 2002; Halson & Jeukendrup, 2004). Ammonia may be reduced during overtraining (Lehmann et al., 1998). However, individual variability in ammonia renders it an unreliable marker (Urhausen & Kindermann, 2002). Despite accepted alterations of multiple biological parameters during exercise, particularly during strenuous exercise, no satisfactory biological markers of overtraining have consistently emerged (Armstrong & VanHeest, 2002; Halson & Jeukendrup, 2004; McKenzie, 1999; Meeusen et al., 2006; Urhausen & Kindermann, 2002). Therefore, research to date is inadequate in discriminating biological parameters among athletes who are overtrained, overreached, or merely intensively trained.

2.2.5.2 Immunological

Moderate exercise is associated with improved immune function (Malm, 2004; Nieman & Pedersen, 1999). A dose-response relationship between exercise and immune function appears to indicate the existence of a threshold, above which exercise may actually harm, instead of benefit athlete immunity. Immune function and the incidence of infections among athletes as possible markers of overtraining have therefore, been extensively investigated. Leukocytes, immunoglobulins, and glutamine are among the most commonly investigated markers of immune function in overtraining research.

Leukocytes and subpopulations

Leukocytes (white blood cells) include subpopulations; neutrophils, monocytes, lymphocytes, and natural killer cells (Shephard & Shek, 1995). Despite some evidence for disturbed leukocyte numbers during intensive training periods, blood leukocyte numbers usually return to normal following rest (Fry, Morton, Crawford & Keast, 1992c; Gleeson, McDonald, Cripps, Pyne, Clancy, & Flicker, 1995; Hooper & Mackinnon, 1995; Mackinnon, Hooper, Jones, Gordon, & Bachmann, 1997). Furthermore, leukocyte numbers were reported to be similar in both well-trained and overtrained elite swimmers (Hooper & Mackinnon, 1995) and unchanged following intense training in professional soccer players (Filaire & Pequignot, 2003). Lymphocyte number increase during exercise, but return, or fall below, pre-exercise values during recovery (Nieman & Pedersen, 1999; Pedersen & Hoffman-Goetz, 2000; Shephard & Shek, 1996). During periods of intense training and overtraining, resting peripheral lymphocyte concentrations appear to be relatively unaffected (Fry et al., 1992c; Fry, Grove, Morton, Mackinnon et al., 1997; Gabriel et al., 1998; Hooper & Mackinnon, 1995; Rowbottom, Keast, Goodman, & Morton, 1995; Zeroni, Gaudieri, & Keast, 1994a). Lymphocyte proliferation (functioning) was increased in some studies following overreaching (Fry et al., 1994a; Gabriel, Urhausen, Valet, Heidelbach, & Kindermann, 1997), but impaired following intensified training in others (Lancaster, Halson, Khan, Drysdale, Wallace, Jeukendrup, Drayson, & Gleeson, 2003; Verde, Thomas, & Shephard, 1992). In overreached athletes, natural killer cell count, but not function, was unaltered in some studies (Fry et al., 1994a; Gabriel et al., 1998), and suppressed in others (Fry et al., 1992c; Gleeson et al., 1995; Rhind, Gannon, Suzui, Shephard, & Shek, 1999; Verde et al., 1992). Neutrophil counts have been reported to be unaltered (Fry et al., 1994a; Gabriel et al., 1998; Mackinnon et al., 1997) or increased (Hooper & Mackinnon, 1995) during overreaching. Monocyte number and function among intensively trained athletes were unaltered in one study (Gabriel et al., 1998), but were reduced in others (Lancaster et al., 2003; Suzuki, Nakaji, Yamada, Lui, Kurakake, Okamura, Kumae, Umeda, & Sugawara, 2003; Woods, Lu, & Lowder, 2000). The consequences of the sometimes observed leukocyte and subpopulation suppressions remain uncertain (Mackinnon, 2000).

Glutamine

Glutamine provides a major fuel source for many cells of the immune system (Ardawi & Newsholme, 1983; Vance, Eggleton, & Castell, 2001), and may also play a role in maintaining proper immune function (Walsh, Blannin, Robson, & Gleeson, 1998). Glutamine is synthesised by various organs including brain, liver, lungs but primarily skeletal muscle (Rowbottom, Keast, & Morton, 1996). Decreased serum concentrations of glutamine have been postulated to be a marker of immunosuppression and overtraining (Parry-Billings, Evans, Calder, & Newsholme, 1990; Parry-Billings et al., 1990b).

The acute effect of intense exercise appears to increase glutamine concentrations approximately 22% immediately post-exercise (Eriksson, Broberg, Björkman, & Wahren, 1985; Maughan & Gleeson, 1988; Sahlin 1990). In contrast, 15 to 25% decreases in plasma glutamine levels were observed following prolonged exercise (Hood & Terjung, 1990; Kingsbury, Kay, & Hjelm, 1998; Parry-Billings, Budgett, Koutedakis, Blomstrand, Brooks, Williams, Calder, Pilling, Baigrie, & Newsholme, 1992; Rohde, Ullum, Rasmussen, Kristensen, Newsholme, & Pedersen, 1995) and overtraining (Mackinnon & Hooper, 1996; Parry-Billings et al., 1992; Rowbottom et al., 1996). No changes have also been reported (Lehmann, Hounker, Dimeo, Heinz, Gastmann, Treis, Steinacker, Keul, Kajewski, Häussinger, 1995). In overreached rugby league players, glutamine has been shown to decrease (Coutts, Reaburn, Piva, & Murphy 2007c, Coutts, et al., 2007a). In professional soccer players, glutamine was lower following intense training (Filaire et al., 2003). Reduced plasma glutamine levels are thought to be more transient than long-term, with levels usually returning to normal within 9 hours (Castell, 2003). Despite some evidence linking overreaching and overtraining with lowered plasma glutamine, it is currently unclear how reliable glutamine is as a marker.

Immunoglobulins

Immunoglobulins (Ig) are a subclass of lymphocyte antibodies (Shephard & Shek, 1996). Clinically low immunoglobulin concentrations have been reported during intense training, overreaching, and overtraining. Serum IgA, IgG, and IgM were significantly lower in elite swimmers than age-matched controls during a seven-month training season (Gleeson et al., 1995). Lowered resting salivary IgA concentrations are not uncommon among some athletes (Gleeson et al., 1995; Gleeson, McDonald, Pyne, Cripps, Francis, Flicker, & Clancy, 1999a; Gleeson, Hall, McDonald, Flanagan, & Clancy, 1999b). A decrease in salivary IgA has been observed during intense training (Halson et al., 2003; Tharp & Barnes, 1990), as well as during periods of overtraining (Mackinnon & Hooper, 1994). An 18 to 32% lower concentration of IgA in three athletes showing signs of overreaching was reported following a comparison with ‘healthy’ athletic peers (Mackinnon & Hooper, 1994). Low salivary IgA levels precede upper respiratory tract infections and correlate well with infection rates (Gleeson et al., 1999a; Mackinnon, Ginn, & Seymour, 1993). However, in overreached or overtrained athletes no consensus exists on the usefulness of IgA as a marker of prolonged maladaptation.

Upper respiratory tract infections (URTI)

Athletes and coaches frequently report an increased incidence of URTI among trained individuals when compared with non-training counterparts (Budgett, 2000a; Halson & Jeukendrup 2004; McKenzie, 1999), and during periods of intensified training and overtraining (Meeusen et al., 2006). The relationship between training and immunity against URTI remains poorly understood (Mackinnon, 2000, Halson & Jeukendrup, 2004; Meeusen et al., 2006). In a study of 24 elite swimmers, a four week increase in training intensity resulted in eight (33%) of the swimmers being classified as overreached. Concurrently, 10 (42%) of the swimmers self-reported having had symptoms of URTI. The rate of URTI was significantly lower among the overreached compared with the normally trained swimmers. In a study of Olympic athletes, over 50% of athletes classified as overtrained presented with URTI while none of the athletes classified as overreached demonstrated URTI symptoms (Kingsbury et al., 1998). In junior rowers there was a 40% incidence of URTI following functional overreaching achieved during a training camp (Steinacker & Lehmann, 2002). In elite distance runners, URTI were not associated with training loads (Fricker, Pyne, Saunders, Cox, Gleeson, & Telford 2005). It would appear that an increased incidence of URTI may be present during periods of intense training independent of whether the training then leads to overtraining (Mackinnon, 2000). Therefore, since the incidence of URTI may reflect training intensity and not overtraining, the usefulness of URTI as a marker of overtraining is questionable.

2.2.5.3 Hormonal

The neuroendocrine system maintains the body’s internal homeostasis and is especially active during periods of strenuous exercise (Armstrong & VanHeest, 2002). Exercise elicits a milieu of normal hormonal responses that play an important role in maintaining balance and regulating training responses (Kraemer

& Ratamess, 2005). Hormonal perturbations deviating from 'normal' may indicate hormonal-mediated central dysregulation. Hormonal dysregulation may coincide or even contribute to overtraining (Meeusen et al., 2006). Monitoring hormones has therefore, widely been proposed as a means of managing and detecting overtraining (Duclos, 2008; Fry, Morton, & Keast, 1991; Fry & Kraemer, 1997; Kuipers & Keizer, 1988; Lehmann, Knizia, Gastmann, Petersen, Khalaf, Bauer, Kerp, & Keul, 1993a; Meeusen, 2004; Steinacker, Lormes, Lui, opitz-Gress, Baller, Gunther, Gasteman, Petersen, Lehmann, & Altenburg, 2000; Steinacker et al., 2004; Urhausen, Gabriel, & Kindermann, 1995). Interpretation of the available literature on hormonal markers is however, confounded by the use of a variety of measuring techniques, differing research methodologies, and the rhythmic, individual, and transient nature of hormonal responses.

Testosterone and cortisol

Acute increases in testosterone are normally observed in response to exercise and are usually unchanged at rest (Kraemer & Ratamess, 2005). Lowered testosterone levels have been demonstrated following intensive training and overtraining (Flynn, Pizza, Boone, Andres, Michaud, & Rodriguez-Zayas, 1994; Fry & Kraemer, 1997; Hakkinen & Pakarinen, 1991; Häkkinen, Pakarinen, Alen, Kauhanen, & Komi, 1988b; Raastad, Bjoro, & Hallen, 2000; Vervoorn, Quist, Vermulst, Erich, de Vries, Thijssen, 1991), but normal testosterone responses were also reported (Fry, Kraemer & Ramsey, 1998; Urhausen 1998a). Cortisol is a stress-related hormone released by the adrenal cortex that (among other physiological functions) affects the availability of energy by controlling certain aspects of metabolism (Hackney, Pearman, & Nowacki, 1990; Kraemer & Ratamess, 2005; Urhausen et al., 1995). Conflicting findings show cortisol concentrations are either elevated at rest (Filaire, Legrand, Lac, & Pequignot, 2004, Maso, Lac, Filaire, Michaux, & Robert, 2004; Fry & Kraemer, 1997; Hakkinen & Pakarinen, 1991) or unchanged (Flynn et al., 1994; Hooper & Mackinnon, 1995; Kraemer & Ratamess, 2005, Mackinnon et al., 1997; Urhausen et al., 1998a) during overreaching and overtraining. Maximal cortisol responses however, decreased in overreached participants (Snyder et al., 1995; Urhausen et al., 1998a; Uusitalo, Huttunen, Hanin, Uusitalo, & Rusko, 1998). Elevated cortisol levels may only serve as an indicator of the stress of training and are therefore, generally not considered to have diagnostic potential for overtrained athletes (Filaire et al., 2004).

A decrease in the ratio of testosterone to cortisol has been explored as a possible marker of overtraining (Adlercreutz, Harkonen, Kuoppasalmi, Näveri, Huhtaniemi, Tikkanen, Remes, Dessypris, & Karvonen, 1986; Gorostiaga, Izquiredo, Iturralde, Ruesta, & Ibáñez, 1999, Hakkinen, Pakarinen, Alen, Kauhanen, & Komi, 1987, Maso et al., 2004; Meeusen et al., 2006). The testosterone / cortisol ratio may reflect the balance between androgenic-anabolic and catabolic activity in the body (Halson & Jeukendrup, 2004). However, testosterone / cortisol ratios have been unchanged in overreached athletes (Flynn et al., 1994; Fry et al., 1998; Lehmann, Gastmann, Petersen, Bachl, Seidel, Khalaf, Fischer, & Keul, 1992b; Maso et al., 2004; Mackinnon et al., 1997; Urhausen et al., 1998a; Uusitalo et al., 1998), decreased in normally trained athletes (Vervoorn et al., 1991), and decreased in overreached athletes (Filaire et al., 2004; Hackney et al., 1990). In general, testosterone / cortisol ratio tends to decrease in relation to training load but this ratio is more likely an indicator of physiological stress. This ratio may not be capable of differentiating between normally trained, overreached and overtrained athletes (Kraemer & Ratamess, 2005; Meeusen et al., 2006).

Pituitary hormones

Pituitary hormones comprise of gonadotrophins (regulate release of reproductive hormones), corticotrophins (regulate secretion of cortisol), somatotrophins (muscle anabolism), thryrotrophins (regulate thyroid hormones) and β-endorphins (Urhausen et al., 1995). The release of pituitary hormones is regulated by the hypothalamus and a negative feedback inhibition acting on the pituitary. Dysfunction of various hypothalamo-pituitary axes has been postulated to occur during overtraining (Fry et al., 1991). Commonly investigated pituitary hormones include luteinising hormone (LH), follicle-stimulating hormone (FSH), adrenocorticotropic hormone (ACTH), growth hormone (GH), GH mediated insulin-like growth factors (IGF), and prolactin (PRL) (Meeusen et al., 2006; Urhausen et al., 1995; Urhausen & Kindermann, 2002). Decreased releases of ACTH, GH, LH and FSH are frequently attributed to abnormal increases in stressors and an inability to cope, and may be associated with overtraining (Barron, Noakes, Levy, Smith, & Millar, 1985; Lehmann, Foster, & Keul, 1993b, Lehmann et al., 1998; Urhausen et al., 1995; Urhausen et al., 1998b; Wittert, Livesey, Espiner, & Donald, 1996). A decreased secretion of ACTH and GH following maximal exercise has been reported (Fry et al., 1998; Urhausen, Gabriel, & Kindermann, 1998b). Similarly, both ACTH and GH were significantly lowered compared with controls after two days of intensive training (Urhausen, Coen, & Kindermann, 2001). Since altered pituitary functioning occurs in response to normal intensive training, reduced ACTH and GH may not be a valid marker of overreaching or overtraining. Therefore, despite perturbations to the normal responses of pituitary hormones during periods of intense training, concentrations appear unable to differentiate normally trained, overreached and overtrained athletes.

Catecholamines

Catecholamines (epinephrine and norepinephrine) regulate metabolic and circulatory responses and adaptations to physical and psychological stressors incurred during intensive training (Urhausen et al., 1995). Catecholamines increase force production, muscle contraction rate, and energy availability by affecting blood distribution, cardiac contractility, respiratory flow, and substrate mobilization (Kjaer & Secher, 1992; Kraemer & Ratamess, 2005). The release of epinephrine and norepinephrine increases in response to acute exercise (Kraemer & Ratamess, 2005; Urhausen et al., 1995). Catecholamine responses to overtraining are inconsistent and efficacy of monitoring them is challenged by their short (~2 minute) half-life and large inter-individual variability (Duclos, 2008). Nocturnal urinary catecholamine excretion has been reported to be lower in overreached and overtrained athletes that may suggest hypothalamo-pituitary-adrenal axis dysfunction (Gleeson, 2002; Lehmann, Schnee, Scheu, Stockhausen,

& Bachl, 1992a; Lehmann et al., 1998, Mackinnon et al., 1997). However, other investigations have not been able to support a link between decreased nocturnal urinary excretion of catecholamines and overtraining in athletes (Hedelin, Kentta, Wiklund, Bjerle, & Henriksson-Larsen, 2000a; Urhausen et al., 1998b; Uusitalo et al., 1998). Elevated resting plasma norepinephrine levels in overtrained athletes have also been reported (Hooper, Mackinnon, Gordon, & Bachmann, 1993, Lehmann et al., 1992b). Nevertheless, the results were unsupported in other studies (Urhausen et al., 1998b). In agreement with the suggested roles of other pituitary moderated hormones, catecholamines could be useful for monitoring the physiological strain associated with training, but may be unable to detect overtraining (Halson & Jeukendrup, 2004).

Cytokines

Cytokines coordinate several aspects of both local and systemic inflammation (Simpson, Hammacher, Smith, Matthews, & Ward, 1997). Cytokines are soluble hormone-like proteins produced by a variety of cells such as immune, endothelial, and fat-storing cells (Smith, 2000b). Cytokines include interleukins (IL), interferons (INF), tumour necrosis factor (TNF), growth factors, and chemokines (Simpson et al., 1997). Cytokines are either pro-inflammatory (IL-1β, IL-6, IL-8, and TNF-α) or anti-inflammatory (IL-4, IL-10, IL-13, and IL-1 receptor antagonist) (Smith, 2000b). Cytokines also play a role in immunity (Robson, 2003; Smith, 2003a) and since lowered immunity as well as inflammatory responses may be associated with overtraining, cytokines have been explored as markers for overtraining. Normal micro trauma resulting from exercise initiates a release of cytokines to act as local inflammatory agents. With continued high-volume and, or, high-intensity training, local inflammation could progress to chronic systemic inflammation, triggering the release of large quantities of pro-inflammatory cytokines (Smith, 2000b). Cytokines increase dose-responsively with exercise (Pedersen & Hoffman-Goetz, 2000; Robson, 2003). Interluekin-6, for example increased following intensive or prolonged exercise (Ostrowski, Rhode, Asp, Schjerling, & Pedersen, 1999; Smith, 2000b; Ullum, Haahr, Diamant, Palmo, Haljaer-Kristensen, & Pedersen, 1994). Immediately following marathon races, IL-6, IL-10, and TFN-α were reported to be elevated (Smith, 2003a; Sondergaard, Ostrowski, Ullum, & Pedersen, 2000). Cytokines respond sensitively and acutely to exercise and are elevated following exercise-induced muscle trauma and, or, injury. However, to date, minimal evidence exists to link cytokine responses and more chronic responses to training including overtraining (Smith, 2000b).

2.2.5.4 Nutrition and metabolic alterations

Macronutrients, particularly carbohydrates, and the subsequent links to metabolic responses to training have been investigated as possible markers of overtraining. Muscle and liver glycogen depletion may accompany states of overtraining because of increased fuel requirements during increased training demands (Armstrong & VanHeest, 2002). Since moderate and intensive exercise is primarily fuelled by glycogen derived glucose, glycogen depletion may well account for performance decrements and fatigue common with overtraining. In double-blinded studies limiting or controlling carbohydrate ingestion, participants showed signs of staleness and a decline in performance when carbohydrate intake failed to meet the energy demands of training (Costill, Flynn, Kirwan, Houmard, Mitchell, Thomas, & Han Park, 1988; Morgan, Costill, Flynn, Raglin, & O'Conner, 1988; Snyder et al., 1995). Although reduced glycogen stores are likely to negatively impact training tolerance, muscle glycogen contents were unaltered in overtrained cyclists (Snyder, Kuipers, Cheng, Servais, & Fransen, 1993b) and are usually normal among overreached or overtrained athletes (Meeusen et al., 2006). The role of glycogen as a marker of overtraining therefore, remains unclear (Armstrong & VanHeest, 2002; Halson & Jeukendrup, 2004).

Compromised metabolism in the absence of any macronutrient depletion has been observed in several studies of intense training and overtraining (Costill et al, 1988; Petibois et al., 2003; Petibois, Melin, Perromat, Carzola, & Déléris, 2000; Snyder et al., 1995). Alterations in metabolism during overtraining in endurance athletes have therefore, been proposed as another potentially reliable marker of overtraining (Petibois et al., 2000). Other studies have however, failed to find alterations in carbohydrate, lipid, amino acid or proteins metabolism during overtraining (Fry et al., 1991). More recently, evidence of reduced metabolism of carbohydrates, lipids, and proteins in overtrained athletes compared with normally trained athletes has been shown. However, this observation was not present at rest and the authors acknowledged that more work is needed to confirm the reliability of the findings (Petibois et al., 2003). It is therefore, unclear whether aspects of exercise metabolism become sufficiently altered during intense training to detect overtraining (Urhausen & Kindermann, 2002).

2.2.5.5 Cardiovascular

Shifts in normal heart rate at rest, submaximal, and maximal intensities as well as heart rate variability have been investigated as possible markers of overtraining (Bosquet, Merkari, Arvisais, & Aubert, 2008). Heart rate is influenced by hormones and the autonomic nervous system and any neuroendocrine disruptions, including either sympathetic or parasympathetic activity may therefore, manifest in alterations in heart rate. Increased resting heart rates among overreached or overtrained participants have been reported in some studies (Dressendorfer, Wade, & Scaff, 1985; Stone, Keith, Kearney, Fleck, Wilson, & Triplett, 1991), while in others increased resting heart rates were not supported (Callister et al., 1990; Fry et al., 1992b; Gabriel et al., 1998; Lehmann et al., 1992b; Snyder et al., 1995; Urhausen et al., 1998a). In addition to resting heart rate changes, intensive training decreased heart rates for submaximal workloads in several studies (Billat, Flechet, Petit, Muriaux, & Koralsztein, 1999; Hedelin et al., 2000a). Reduced maximal heart rates following intensive training have been found in some studies (Hedelin et al., 2000a; Jeukendrup et al., 1992; Lehmann et al., 1991; Urhausen et al., 1998a), but not others (Billatt et al., 1999). Despite observations of heart rate alterations, individual variability makes it difficult to discriminate among participants who are fatigued, overreached or overtrained. Therefore, additional research is required to link changes in, resting, submaximal or maximal heart rates with overtraining (Bosquet et al., 2008; Halson & Jeukendrup, 2004).

Heart rate variability (HRV) refers to the oscillation in the time interval between consecutive beats (R-R) and is used as a measure of cardiac autonomic balance (Achten & Jeukendrup, 2003; Halson & Jeukendrup, 2004). Heart rate variability may be a useful measure for monitoring the training response with one study showing increased HRV following 12 weeks of endurance training (Carter, Bannister, & Blaber, 2003). The measure of HRV in overreaching and overtraining research as a marker has revealed conflicting results with studies showing either no changes (Achten & Jeukendrup, 2003, Bosquet, Papelier, Leger, & Legros, 2003; Hedelin et al., 2000a; Uusitalo et al., 1998), inconsistent changes (Uusitalo, Uusitalo, & Rusko, 2000), or increases in HRV (Hedelin, Urban, Bjerle, & Henriksson-Larsen, 2000b). A 50% increase in the training load of 9 canoeists over a 6 day training camp resulted in decreases to maximal blood lactate production and heart rate but had no effect on HRV (Hedelin et al., 2000a). Increasing training load for 6-9 weeks in female athletes also produced no significant alterations in HRV (Uusitalo et al., 1998). Compared with baseline measures, an increase in HRV was reported in a single overtrained cross-country skier (Hedelin et al., 2000b). However, large, well controlled studies investigating the plausibility of HRV as a marker of overtraining are lacking (Meeusen et al., 2006). Until such studies are conducted, the use of HRV as a marker of overtraining is not supported.

2.2.6 Psychological markers of overtraining

While the efficacy of physiological markers for detecting overtraining remains unclear, general consensus supports the monitoring of psychological variables as a sensitive and reliable means of detecting and therefore, preventing overtraining (Hooper & Mackinnon, 1995; McKenzie, 1999; Raglin, Eksten, & Garl, 1995; Shephard & Shek, 1994; Urhausen et al., 1998a). Serially measuring psychological variables is an accepted procedure for assessing responses to training load and the resulting stress experienced by athletes (Morgan et al., 1987). A clearly delineated dose-response relationship exists between training load and psychological states such that increases in training load consistently result in increased psychological perturbations (Berger, Motl, Butki, Martin, Wilkinson, & Owen, 1999; Filaire et al., 2004; O'Connor, Morgan, & Raglin, 1991; Pierce, 2002). Psychological markers of overtraining have been additionally attractive from a research perspective because data collection is cost effective and results are easily analysed (Hollander, Meyers, & LeUnes, 1995; Fry et al., 1994a; Kenttä & Hassmén, 1998; Shephard & Shek, 1994). It is on these premises that researchers have investigated multiple psychological variables as a means of detecting deleterious effects of training leading to overtraining.

Overtraining is frequently associated with negative psychological states including anxiety, depression, fatigue, lethargy, anger, lack of self-esteem, mood disturbances, increased stress, decreased recovery, elevated perceived effort, disturbed sleep, and lack of concentration (Fry et al., 1994a; Kellmann, 2002;

Raglin, Morgan, & Luchsinger, 1990; Raglin et al., 2000; Urhausen & Kindermann, 2002). It is not always known whether such negative psychological states are the result or the cause of overtraining. Nevertheless, measurable shifts from normal or baseline values are often observed during periods of intense training and, or, overtraining. Psychological states may therefore, be sensitive and reliable enough for early detection and ultimately contribute to overtraining prevention. Although not mutually exclusive, athlete psychological profiles have been investigated from at least three primary perspectives, mood states, stress and recovery, and subjective complaints. Mood states appear to be among the most reactive psychological variables and have therefore, received much attention in the literature. More recently, subjective ratings of stress and recovery have been used to monitor the psychological effects of training. Lastly, perceived effort for a given workload and subjective complaints have proved a simple and reliable means of assessing psychological states in response to training stressors.

2.2.6.1 Mood states

Mood comprises of a myriad of transient emotions including anger, depression, anxiety, and fatigue (Feigley, 1984; Raglin et al., 1990). Being transient in nature, mood appears highly responsive to environmental cues such as training stressors. Mood state as a marker of training stress and overtraining has therefore, been researched intensively using a variety of psychological instruments. The most consistent findings from psychometric research have been increased negative mood states during periods of intensive training that return to normal states following periods of recovery or reduced training load (Meehan, Bull, Wood, & James, 2004; Morgan et al., 1987; O'Connor et al., 1991). While monitoring mood state appears to be a valid means of detecting training stressors and athlete resilience, the ability of altered mood to distinguish a normal training response from one resulting in overtraining is less clear.

Monitoring mood states, particularly in response to increased training loads has produced reasonably consistent findings with only some researchers unable to replicate the most common findings. Using a psychological instrument called the Profile of Mood States (McNair, Lorr, & Droppelmann, 1992), the mood states of 400 competitive male and female swimmers were monitored across a ten year period. The major finding from this study was that a dose-response relationship existed between mood state and training intensity. This led the authors to posit that mood state could be a useful means of detecting and preventing overtraining (Morgan et al., 1987). These findings were later supported in collegiate swimmers across a 21-week competitive season (Flynn et al., 1994), in male and female swimmers following three days of increased training intensity (O'Connor et al., 1991), and in male and female swimmers following a 24-week competitive season (Pierce, 2002). Negative mood states were recorded in eleven elite kayakers during a three-week training camp, supporting a dose-response relationship between training intensity and mood state (Kenttä, Hassmén, & Raglin, 2006). In a study of 272 athletes across 16 sports, mood disturbances consistently increased in response to increased training intensities (Kenttä, Hassmén, & Raglin, 2001). In contrast, a four day increase in training load failed to induce mood disturbances in

12 elite cyclists (Filaire et al., 2004). Soccer players also failed to demonstrate changes in mood state following 7 weeks of high-intensity training (Filaire, Bernain, Sagnol, & Lac, 2001). Similarly, mood state was unaltered in 11 cyclists following six weeks of high-intensity interval training (Martin, Andersen, & Gates, 2000). No changes in mood state following periods of tapering or reduced training have also been observed (Callister et al., 1990; Hooper et al., 1997). Despite conflicting findings, most research supports the existence of a dose-response relationship between training stressors and mood state.

Since mood state can reflect training stress, the efficacy of mood state monitoring as a marker of overtraining has been explored. Increased negative mood state has been reported to be a sensitive and reliable marker of overtraining (Barron et al., 1985; Foster, 1998; Fry et al., 1991; Fry et al., 1994a; Halson, Bridge, Meeusen, Busschaert, Gleeson, Jones, & Jeukendrup 2002; Hooper et al., 1997; Main, Dawson, Grove, Landers, & Goodman 2009; Morgan et al., 1987; Snyder, Jeukendrup, Hesselink, Kuipers, & Foster, 1993a; Urhausen et al., 1998a; Urhausen et al., 1998b). When overtraining was induced in eight experienced runners during a four-week period, athletes self-reported negative mood state increased significantly and was found to correlate with increases in physiological markers of overtraining (Lehmann et al., 1991). Male cyclists and triathletes recorded greater negative mood states during periods of overtraining compared with normal training periods (Urhausen et al., 1998a). In a study of adolescent swimmers from four countries, stale swimmers from three of the four countries exhibited significantly greater negative mood states during periods of staleness

(Raglin et al., 2000). Negative mood states in overtrained athletes have also been reported in a study that induced overtraining in five male athletes over a ten day period (Fry et al., 1994a). The ability of mood state to detect overtraining is not a consistent finding with results from some studies unable to show greater mood disturbances in overtrained compared with normally trained athletes (Hooper et al., 1997), and others reporting a high level of individual variability in mood state alterations (Meehan et al., 2004). Furthermore, because negative mood state increases during periods of intensified training that do not lead to overtraining, monitoring mood state alone may not provide a sufficient means of detecting overtraining.

Within studies of mood state, depression has received particular attention because of distinct similarities between the signs and symptoms of overtraining and major depression (Fry et al., 1991). Signs of major depression include negative thoughts, feelings, physical health, behaviours, and functioning (Armstrong & VanHeest, 2002). These signs of depression as well as depression itself are often synonyms with overtrained athletes (Lehman, Foster, & Keul, 1993b; Puffer & McShane, 1992; Stone et al., 1991). However, among elite swimmers, depression was not found to accompany a single stale swimmer who recorded normal psychometric depression scores (Hooper et al., 1997). While evidence of strong links between major depression and overtraining exists, further investigations are required to determine the efficacy of depression as a marker of overtraining.

2.2.6.2 Stress and recovery

Monitoring mood states alone as a marker of training load and overtraining has recently been challenged by the argument that key aspects of the aetiology of the overtraining may not be addressed by negative mood states (Kellmann, Altenburg, Lormes, & Steinacker, 2001b; Kellmann & Günter, 2000; Kenttä & Hassmén, 1998; Mästu, Jürimäe, Kreegipuu, & Jürimäe, 2006). Subjective ratings of stress and recovery may be an additionally useful method of monitoring the psychological state of athletes and thus, detecting and preventing overtraining (Kellmann & Günter, 2000). Stress has been defined as an asynchronous state between change within an individual and change within the environment (Chiroboga, 1982; Mäestu et al., 2006). In athletes, stress is accompanied by elevated anxiety, anger, and decreases in performance and motivation to participate (Kellmann & Günter, 2000; Silva, 1990). Recovery is the elimination of stress and the restoration of psychological and physiological resources (Kellmann 2002). The recovery-stress state therefore, represents the extent to which an individual is physically and, or, psychologically stressed as well as whether or not that individual is capable of using individual recovery strategies to overcome stressors (Kellmann et al., 2001b). In agreement with the relationship between training and mood state, studies that have evaluated the stress-recovery model have established a dose-response relationship exists between training load and stress and recovery. In a study of 24 female and 30 male rowers leading into the world rowing championships, stress and recovery was assessed over a six-week training camp. Results showed that as training load increased, stress increased, and recovery decreased (Kellmann et al., 2001b). Stress and recovery were negatively affected following a six-day intensive training camp in another 21 competitive male rowers (Jürimäe, Mäestu, Purge, & Jürimäe, 2004). The recovery-stress response to intense training periods has also been supported by several other studies (Coutts, Reaburn, 2008; Coutts, Wallace, & Slattery, 2007b; Gonzalez-Boto, Slaguero, Tuero, Gonzalez-Gallego, & Marquez, 2008; Jürimäe, Mäestu, Purge, Jürimäe, & Sööt, 2002; Kellmann & Günter, 2000; Maestu et al., 2006; Steinacker et al., 2000). In 12 male national level rowers training was increased for three weeks followed by a two-week recovery period. Following the intensified training period athletes classified as overreached demonstrated an increase in stress and a decrease in recovery. When compared with the normally trained athletes in this cohort, one athlete classified as overtrained demonstrated a greater negative stress-recovery state (Maestu et al., 2006). In overtrained athletes, subjective ratings of stress and recovery may negatively alter just prior to a diagnosis of overtraining (Kellmann & Kallus, 1999). The well established link between burnout and chronic stress further supports the potential usefulness of monitoring athlete stress (Cordes & Doherty, 1993; Raedeke & Smith, 2004; Smith, 1986). Assessing athlete stress and recovery may therefore, prove a useful means of detecting and preventing overtraining.

2.2.6.3 Perceived effort and subjective complaints

In addition to mood states and stress and recovery, the perception of effort and subjective complaints may provide a simple and effective means of monitoring training adaptations and overtraining (Fry et al., 1994a; Hooper & Mackinnon, 1995; Kenttä & Hassmén, 1998; Morgan et al., 1987; Morgan, 1994; Raglin et al., 2000; Snyder et al., 1993a; Urhausen et al., 1998a; Varlet- Marie, Gaudard, Mercier, Bressolle, & Brun, 2003; Watt & Grove, 1993). Increased perception of effort and subjective complaints are consistently associated with intense training and overtraining (Kenttä & Hassmén, 1998; Raglin et al., 2000). Perception of effort is most frequently measured using the ratings of perceived exertion (RPE) scale (Borg, 1982). Rate of perceived exertion is a useful means of monitoring normal training responses since it correlates well with physiological measures of physical stress such as heart rate and lactate. Rate of perceived exertion may therefore, reasonably accurately estimate intensity (Morgan, 1994; Morgan et al., 1987; Watt & Grove, 1993). Rate of perceived exertion may therefore, be useful in detecting overtraining either by detecting impacts of high loads or by indicating when the perception of effort no longer parallels the external load being applied. One study demonstrated that for a given workload, perception of effort increased in athletes who experienced staleness (Morgan, 1994). In adolescent swimmers, perception of training effort increased significantly during periods of staleness (Raglin et al., 2000). The blood lactate / RPE ratio has also been proposed as a reliable predictor of staleness (Snyder et al., 1993a). Recently, blood lactate / RPE ratio was not different in intensely trained and normal training endurance athletes (Coutts, et al., 2007b).

Measures of subjective complaints including muscular soreness, heavy legs, disturbed sleep, loss of appetite, and increased fatigue have been included in several overtraining studies (Hooper & Mackinnon, 1995; Kenttä et al., 2001; Urhausen et al., 1998a; Urhausen & Kindermann, 2002; Varlet-Marie et al., 2003). In 14 elite swimmers, a well-being rating based on self-reported sleep quality, fatigue, stress, and muscular soreness accounted for the greatest proportion of variance in staleness. Such measures may provide an efficient means of monitoring overtraining and recovery (Hooper & Mackinnon, 1995). The most frequently observed symptoms in overtrained endurance athletes were feelings of heavy legs and muscular soreness, followed by complaints of fatigue, disturbed sleep, and loss of appetite (Urhausen et al., 1998a). In a cohort of 272 elite adolescent athletes from 16 different sports, stale athletes frequently reported increased feelings of heaviness, muscle soreness, sleep disturbances, and loss of appetite (Kenttä et al., 2001). Furthermore, feelings of heavy legs have been related to haematological markers of overtraining (Varlet-Marie et al., 2003). Other studies have reported increased feelings of heaviness among stale athletes, but no changes in sleep quality and appetite (Raglin et al., 2000). Subjective ratings of effort and physical complaints may be useful tools for longitudinal monitoring of athletes and the detection and prevention of overtraining. Subjective ratings are also attractive given the ease with which they can be assessed.

2.2.7 Performance markers of overtraining

Consistent diagnostic markers of overtraining from physiological and psychological measures remain difficult to find. However, decreased physical performance is often considered a gold standard marker of overtraining (Halson & Jeukendrup, 2004; Meeusen et al., 2006; Smith, 2003a; Urhausen & Kindermann, 2002). Indeed, many contemporary definitions acknowledge performance decrements as fundamental in the diagnosis of the overtraining (Budgett et al., 2000b; Halson & Jeukendrup, 2004; Kenttä & Hassmén, 1998; Kreider et al., 1998; Urhausen & Kindermann, 2002). In spite of performance decrements being widely credited as a reliable marker of overtraining, the ability to detect overtraining from performance measures has proven difficult. Assessing performance in team sports using single field or laboratory measures that often poorly reflect game performances is a major challenge. Determining if any decrements in performance exist is therefore, difficult in open chain sports. Furthermore, reliably measuring performance among adolescent athletes for whom performance measures show very high test-retest variability (Abbott & Collins, 2002), may not be possible.

Compromised performance can manifest as either a chronic decline in performance from previous levels or as a plateau, despite maintained or even increased training loads from which improvements are expected (Urhausen et al., 1995; Meeusen, 2004). Athletic performance is a complex construct requiring the coordinated integration of physiological, psychological, tactical, and biomechanical components executed in a competitive and often unstable environment (Smith, 2003b). Any observable decrements or plateaus in performance could be the breakdown of a single or any combination of these specific components. The multi-factorial nature of performance and the need to understand specific causes for performance decrements for the purpose of exclusion, remain among the greatest challenges to quantifying performance and subsequently using it diagnostically. Furthermore, accurate assessment of performance, a challenge in itself, is essential for detection of overtraining (Budgett et al., 2000b; Halson & Jeukendrup, 2004; Urhausen et al., 1995). Few sport specific testing procedures, sensitive enough to detect small performance decrements or alterations to expected responses exist in applied sports science.

Many factors, including the type and duration of performance testing impact on the specific aspect of performance measured as well as test accuracy and sensitivity (Meeusen et al., 2006). Time to fatigue, time trials, repeated measures, incremental submaximal, maximal, and supramaximal testing are among some of the protocols used to attempt to quantify performance. In overtraining studies, alactic anaerobic performances are typically unaltered (Callister et al., 1990; Urhausen et al., 1998a), but decrements have been reported in one study (Flynn et al., 1994). In overtrained strength athletes a reduction in strength measured by a 1 repetition maximum has been observed (Fry, Kraemer, Van Borselen, Lynch, Marsit, Roy, Triplett, & Knuttgen, 1994b). Laboratory testing of $\dot{V}O_{2max}$ typically show a reduced maximal aerobic capacity in overtrained or intensely trained athletes (Adams & Kirkby, 2001; Coutts et al., 2007a; Lehmann et al., 1992b; Smith & Norris, 2000a; Snyder et al., 1993a; Uusitalo et al., 1998), but unchanged values are not uncommon (Callister et al., 1990; Costill et al., 1988; Fry et al., 1992b; Urhausen et al., 1998a). Incremental cycle tests to maximal effort elicited a 3 to 4% decline in maximal aerobic capacity in overtrained cyclists (Jeukendrup et al., 1992; Snyder et al., 1995). When the same participants were re-tested using a time trial test, a slightly larger decline of approximately 5% was observed (Jeukendrup et al., 1992). Using supramaximal exercise tests to fatigue a reduction in time to exhaustion of between 14 to 29% was observed in overtrained individuals (Fry et al., 1992b; Gabriel et al., 1998; Urhausen et al., 1998a). In a field-based study of triathletes, experimentally manipulating training loads resulted in decrements in 3 km time-trial and five-bound test performances among intensely trained (overreached) subjects (Coutts et al., 2007b).

Quantifying performance in team sports is challenging and relatively few team sport overreaching and overtraining studies exist. Recently, experimentally overreached semi-professional rugby league players performed worse in multistage fitness tests and demonstrated reduced $\dot{V}O_{2max}$ following six weeks of intensified training load (Coutts et al., 2007a). This study demonstrated the efficacy of monitoring performance in team sport athletes. Similarly, increased training loads in college American football players induced a state of non-functional overreaching with decreased strength and power performances (Moore & Fry, 2007). Compromised performances may not always present in single bout testing, since athletes experiencing overtraining may only have a reduced capacity for repeated efforts. Overtrained athletes may be able to commence exercise without any observable impairment, but may be unable to complete training or competition as usual (Meeusen et al., 2006; Meeusen, 2004). Repeated measures testing may therefore, provide additional insight into the impact of overtraining on performance although such protocols are yet to be determined. For team sports, repeated effort tests could also better replicate game demands and therefore, be more sensitive to game specific performance changes.

2.2.8 Section summary

Successful performances require a careful balance between training stimuli and recovery processes relative to individual athlete's capacities to adapt. However, in practice, determining an optimal balance is challenging. An accumulation of training (and non-training) stressors with insufficient recovery sometimes occurs, resulting in maladaptations including undesirable training outcomes such as overtraining. Multiple definitions for training processes and deleterious training outcomes exist. For the purposes of this thesis overtraining will be considered an accumulation of excessive, intensive training and non-training stressors coupled with insufficient or inadequate recovery resulting in any deleterious outcomes severe enough to constitute maladaptation.

The indiscriminate relationship between normal intensive training, overreaching, and overtraining, as well as the incoherent presentation of markers of overtraining in individual athletes, has made detecting overtraining difficult. Consequently, relatively few studies have quantified the incidence of overtraining. Nevertheless, adolescent athletes may be a particularly vulnerable population. Current adolescent training approaches and sporting pathways have an increased focus on attaining peak performance and identifying and developing talent. But, these approaches may have concomitantly increased the risk of young athletes overtraining when not appropriately prescribed or managed. Efforts to monitor the training response, including detecting overtraining has led to extensive research into physiological, psychological, and performance based markers. Physiological markers have largely produced variable and inconsistent findings with regards to diagnostic potential. Additionally, many of these measures are difficult to obtain and impractical for longitudinal, field-based monitoring of athletes. Psychometric analyses appear to sensitively reflect negative training responses. Psychological detection may occur early enough to allow coaches and trainers to titrate training loads. Psychological measures also have the advantage of being simple, non-invasive, and cost effective. Psychological markers are however, not without limitations. There is the possibility of athletes manipulating responses to questionnaires or interviews from fear of losing playing time, and social pressures to underplay psychological distress. Performance testing is an integral part of monitoring training responses, and while simple performance measures with diagnostic potential are emerging, adapting performance tests for the detection of overtraining has not been a simple endeavour.

2.3 Quantifying and monitoring load in team sports

2.3.1 Introduction

Adaptation to training for sport is influenced by the volume (frequency × duration), intensity, and timing of all physical exertion (Borresen & Lambert, 2009; Smith, 2003b). Combined, these variables reflect ‘load’ defined as the product of volume and intensity. For the purpose of this thesis physical loading has been termed ‘participation loads’. It is necessary to accurately quantify and serially monitor training and competition loads to systematically implement training and recovery that optimises training responses for improving performance and minimises the risk of maladaptation (Halson & Jeukendrup, 2004; Payne & Hassmén, 1998; Meeusen et al., 2006; Mountjoy, Armstrong, Bizzini, Blimke, Evans, Gerrard, Hangen, Knoll, Micheli, Sangenis, & Van Mechelen, 2008; Smith, 2003b). Indeed, quantifying and monitoring loads is the premise for periodisation of training, a well regarded strategy for balancing stimuli, recovery, and adaptation (Bompa, 1996). Further, since individual athletes are likely to respond differently to a standardised load (Bangsbo, 1994; Hoff, Wislöff, Engen, Kemi, & Helgerud, 2002), effective monitoring of loads accounts for the variance in individual responses. Quantifying and monitoring load is therefore, most successful when it attempts to estimate effects on individual athletes (Smith 2003b). Consequently, load monitoring systems are useful for systematic planning of training, for identifying individual athletes demonstrating signs of maladaptation, and facilitating the titrating of participation loads accordingly.

Quantifying participation loads typically involves either subjective and, or, objective measures of volume and intensity. Additionally, since athletes respond differently to a standardised load, loads can also reflect absolute (external), or relative (internal) demands. A variety of methods exist to determine load. External measures of physical volume (e.g. distance or duration) and intensity (e.g. velocity or number of sprints) can be determined subjectively through training diaries, self-reporting or coach assessment. Alternatively, load can be estimated objectively through direct observation or time-motion analysis. Additional measures also useful for quantifying and monitoring physical loads include heart rate and rating of perceived exertion monitoring that theoretically reflect internal responses to external loading. Given that load is a product of intensity and volume and therefore, multifactorial, single measures of load usually provide limited information about demands. In some sports, single measures of load may be useful. Endurance athletes for example, often use training volume (kilometres/week) to monitor load. This simple measure is however, limited by the absence of measures of intensity. However, for many sports, monitoring load is more challenging. In team sports, participation loads reflect a variety of training modalities (endurance, power, strength, speed) often performed at a range of intensities concurrently in single training sessions and in an unpredictable manner. The multi-dimensional nature of team sports subsequently makes quantifying load difficult, and challenges the efficacy of simply monitoring volume. Despite methodological constraints for monitoring load in team sports, including a lack of valid and reliable measures and the need for measures to be practical, efforts to describe load and establish acceptable monitoring systems should continue. Therefore, in addition to more traditional methods of monitoring load, recent developments in time-motion analysis technology and indices of training stress will be reviewed.

2.3.2 External measures of load

2.3.2.1 Self-reporting

Questionnaires and training diaries are often used to quantify participation loads by assessing the volume of training and competition (distance covered, weekly duration, or number of session and games). These self-reporting methods are attractive due to ease of administration to large number of athletes and are relatively cost effective. Questionnaires are usually the least accurate, and are often associated with limited validity and reliability (Hopkins, 1991; Shephard, 2003). Training diaries may represent a pragmatic means of serially measuring athlete participation loads but, several limitations also exist (Hopkins, 1991). Subjective reporting in diaries is susceptible to athlete perceptions, recall capacity, bias by pressures to appear to be training in a particular way or simply, human error. The relationship between self-reported measures and actual measures of training volume was evaluated among 29 athletes. Twenty-four per cent of participants overestimated, 17% underestimated, and 59% accurately estimated weekly training volume (Borresen & Lambert, 2006). Within these limitations, training diaries are frequently used to monitor participation.

2.3.2.2 Time-motion analyses

Time-motion analysis is the measurement of sport-specific physical and skill-based activities performed during either training or competition. In addition to being a largely objective technique, a major advantage of time-motion analyses is the ability to quantify a wide range of performance aspects within team sports. Quantifying the plethora of performance demands is a traditionally difficult undertaking given the intermittent and unpredictable nature of player movement patterns in team sports. Consequently, a number of different time-motion analysis methods have been used to assess performances in numerous team sports. Time-motion analysis measures performance and assesses athlete horizontal (locomotor) work for a range of applications. Uses include; understanding the demands and performance characteristics for various levels of competition, positions, and different sports, detecting patterns of player fatigue, and improving training specificity. Most time-motion analysis methods, but especially increasingly precise contemporary techniques, also provide a useful and sometimes practical means of objectively quantifying and monitoring external loads in team sports.

Time, distance, and velocity data from time-motion analyses are used to generate information such as distance covered, average and maximal velocity, time, and distance in different locomotor speed zones, work to rest ratios, game-specific skills, and number and pattern of sprint efforts. More advanced systems are now capable of additional measures of accelerations, decelerations, impacts (integrated triaxial accelerometers), and multidirectional movements. Thus, advanced time-motion analysis systems provide extensive information on the physical demands of competition and training. Time-motion analysis continues to be an area of ongoing development that has benefited significantly from advances in technology. Three main technological approaches have been explored and subsequently developed as commercially available analytical tools; video-based tracking (manual and automated), radio frequency, and Global Positioning Satellite (GPS) systems (Carling, Bloomfield, Nelsen, & Reilly, 2008). While all methods produce essentially similar data, each has specific advantages and is constrained by different limitations that will briefly be reviewed.

Original time-motion techniques involved manual analyses of video footage of individual players during competition. To some extent manual video analysis methods continue to be used and, providing observers are adequately skilled, may provide accurate and reliable measures of player movement patterns and skilled events (Deutsch, Kearney, & Rehrer, 2007; Deutsch, Maw, Jenkins, & Reaburn, 1998; Duthie, Pyne, & Hooper, 2005; Mohr, Krustrup, & Bangsbo, 2003). The laborious analytical process and subjectivity in determining movement patterns are however, significant limiting factors. More recently, video analysis methods based on trigonometric techniques have been developed. These include automated multi-camera systems using specific algorithms to calculate player position. While automated camera systems have the advantage of being able to analyse multiple players simultaneously, they are cost prohibitive, need to be permanently installed at stadiums, and usually require some degree of manual expertise to limit errors associated with the automated process (Barros, Misuta, Menezes, Figueroa, Moura, Cunha, Anido, & Leite, 2007; Di Salvo, Collins, McNeill, & Cardinale, 2006). With advancing technology, radio frequency systems have become an alternate time-motion analysis technique. Radio frequency uses electronic transmitting microchips worn by players to send radio signals to antennae receivers located around the field. Radio frequency is capable of a high sampling rate with a potential high accuracy. However, use of radio frequency may be constrained by the distance signals need to travel in field settings and a potential for signal interference (Edgecomb & Norton, 2006). Furthermore, the efficacy of this technology is yet to be validated. Other recent developments in time-motion analysis techniques include Global Positioning Satellite (GPS) systems and manual tracking software used in conjunction with video footage (referred to as computer-based tracking) (Edgecomb & Norton, 2006). Given these methods were used in this thesis, GPS and computer-based tracking will be discussed in more detail.

No single gold-standard time-motion analysis system exists. Therefore, a major consideration for using time-motion analyses to quantify external load is the reliability, validity and practicality of methods employed. In general, time-motion analysis methods are limited by; cost, game laws (e.g. systems that require players to wear equipment are not permitted during competition in many team sports), time required for analysis, hardware, software error, user error, and environmental factors (Dobson & Koegh, 2007; Macleod, Morris, Nevill, & Sunderland, 2009). To minimise the likely impact of these factors on measurement accuracy, time-motion analysis methods should be evaluated for reliability and validity, be applied using standardised procedures and factor in the efficacy of their use in different situations. Where manual data collection or data analysis procedures are involved, an evaluation of inter- and intra-tester reliability should be undertaken. Similarly, where analysis is automated, measurement error should be calculated by determining system or intra-method reliability. Also, where possible, time-motion analysis methods should be evaluated against established methods of measurement (such as other time-motion methods, chronometry, and more precise odometer distance measures) for criterion validity (Carling et al., 2008; Dobson & Koegh, 2007; Witte & Wilson, 2004).

Global positioning systems (GPS)

The development of commercially available sport-specific GPS devices has resulted in an exponential increase in reports of time-motion analysis in research studies and among many professional sports. Global Positioning Systems use a network of earth orbiting satellites to communicate with ground based GPS receiver units. Satellites emit, at the speed light, atomic clock data received by GPS devices. By emitting radio signals between at least four satellites and a receiving device, and comparing the signal travel time, the exact positional location of the receiver can be triangulated trigonometrically (Larsson, 2003; Witte & Wilson, 2004). Accuracy of the system is influenced by radio wave obstructions (e.g. stadiums and cloud cover), number of satellites available, geographical orientation of satellites, and specific algorithms used for distance and velocity calculations (Williams & Morgan, 2009; Witte & Wilson, 2004). An advantage of GPS over other time-motion analysis techniques is the ability to simultaneously collect data from a number of players. Use is limited only by the number of GPS units available. Data analysis is also automated, which makes results readily available for interpretation. In addition to being restricted to outdoor use, to date a major limiting factor has been the inability to use GPS devices in competitive games for many team sports. Laws in rugby union for example, do not permit the use of GPS units in games for player safety reasons. Consequently, GPS time-motion analysis has been limited to training and friendly games. Nevertheless, the practical advantages of this method over more time consuming video-based techniques make GPS a widely attractive method.

Validity and reliability studies have produced equivocal results on the ability of GPS to measure distance and velocity. In one of the first studies to assess commercially available GPS devices (1 Hz SPI 10 model, GPSports Systems Pty Ltd 2003, Canberra, Australia), validity tests of GPS distance compared to trundle wheel distance found an average 4.8% tendency for GPS to overestimate distance and a triplicate intra-tester reliability (TEM) of 5.5% (Edgecomb & Norton, 2006). However, tests were conducted using a circular running path and did not reflect the type of movement patterns routinely occurring in team sports. Using a different 1 Hz GPS system (REB 2100, RoyalTek, Taiwan), validity of GPS to measure distance and velocity of cycling in straight and circular paths has been assessed. Results showed good accuracy for distance measurements, but not when rapid changes in speed or direction were involved (Witte & Wilson, 2004). These results contrasted with other similar studies (Edgecomb & Norton, 2006). Reasons for the lower measurement accuracy could include the higher velocities attained during cycling compared with running and differences in algorithms used by each commercial system to calculate distance and velocity data. However, this does not account for results in another study in which the accuracy of GPS to measure distance at low velocities was good, but poor (standard error of estimates between 3 and 11%) during sprinting (Petersen, Pyne, Portus, & Dawson, 2009).

Recently, a field hockey specific circuit was designed to determine the validity of GPS (1 Hz, SPI elite model, Systems Pty Ltd 2003, Canberra, Australia) for assessing team sport movement patterns (Macleod et al., 2009). Using 95% limits of agreement, criterion validity of various speeds, distances and movement patterns were assessed. Results showed strong Pearson correlations between actual and GPS measures for all speed, distance, and movement pattern variables. Additionally, 95% limits of agreement were small. From these results it was concluded that GPS is a valid method for determining player movement patterns in intermittent team sports such as field hockey (Macleod et al., 2009). Similarly, a study designed to determine the validity and reliability of various GPS devices, including the 1 Hz SPI 10 model, for measuring movement during high-intensity, intermittent exercise, reported acceptable validity and reliability for total distance and peak speeds, but poor inter-unit reliability for distance travelled at high intensities (Coutts & Duffield, 2008). This conclusion has been supported by other studies finding similar accuracy for measuring locomotor patterns using 1 Hz GPS systems (Townshend, Worringham, & Stewart, 2008). Therefore, despite some findings to the contrary and evidence of some systematic errors, commercially available GPS systems appear capable of generating time-motion analysis data with adequate accuracy for applied sport settings. Current GPS systems are therefore, within limitations, a practical means of assessing performance variables and quantifying and monitoring load in team sports.

Computer based tracking (CBT)

The practical limitation of not being able to use GPS during competitive games can be overcome by using video-based time-motion analysis. As previously discussed, many different video-based systems exist. In this thesis, individual player analyses during games were conducted using a system called ‘Trak Performance’ (Sports Tec Pty Ltd, Australia). Trak Performance allows researchers to observe video footage (or real time) of a single player and simultaneously ‘track’ the players movement patterns on a miniaturised scaled drawing of the playing field using a drawing tablet and stylus pen. Accuracy of this method relies on observer skill and quality of video footage used for analysis. Analysis also relies on spatial references within video frames such as field markings to help determine players’ relative position on the field.

The validity and reliability of this system is generally reported high for measures of distance and velocity, providing observers are highly skilled (Burgess, Naughton, & Norton, 2006; Edgecomb & Norton, 2006; Sirotic, Coutts, Knowles, & Catterick, 2009). The results from an investigation of the validity and reliability of computer-based tracking showed that Trak Performance was both valid and reliable within an acceptable range of error for monitoring distance in team sports (Edgecomb & Norton, 2006). In this study, actual and CBT determined distances showed strong correlations (r=0.999) with an average CBT overestimation error of 5.8%. Repeated measures showed inter-tester TEMs of approximately 9%. Other studies have reported intra-tester TEMs of 4.6% and Pearson correlations of r=0.98 for distance covered during Australian Football matches (Burgess et al., 2006). Most recently, CBT was used to compare match demands in different level rugby league teams. Authors noted that while systematic errors are associated with this method of time-motion analysis, these errors are not problematic, if results are interpreted with consideration of the size of measurement error relative to the measurements observed (Sirotic et al., 2009; Sirotic & Coutts, 2008).

2.3.3 Internal measures of load

2.3.3.1 Heart rate and indices of load

Heart rate (HR)

Monitoring heart rate as a means of determining intensity is common practice among many athletes (Achten & Jeukendrup, 2003). Heart rate as a measure of intensity is based on the theoretical assumption of linearity between HR, steady-state work rate and oxygen consumption (Arts & Kuipers, 1994). In conditions under which linearity is achieved, HR accurately estimates physiological cost and therefore, exercise intensity. Heart rate data are normally represented as a per cent of maximum, however, % of $HR_{reserve}$ (HR_{max} –HR_{rest}) accounts for individual differences in resting and maximal HR and may be more accurate (Karvonen & Vuorimaa, 1988). In practice, many factors may influence the linear relationship between HR and workload, and thus alter the accuracy of HR as a measure of intensity. Day to day variations in HR may be as high as 6.5% (Bagger, Petersen, & Pedersen, 2003) and HR is easily influenced by environmental conditions (Achten & Jeukendrup, 2003), cardiac drift (Coyle, 1998), hydration (González-

Alonso, Mora-Rodriguez, Below, & Coyle, 1997), medication (Borresen & Lambert, 2009), emotions, body composition, and altitude (Vogel, Hansen & Harris, 1967).

In addition to limitations for monitoring intensity using HR, in team sports in which steady-state workloads are rarely performed, HR tends to reflect intensity with less accuracy. Heart rate can also be a relatively imprecise method of assessing the intensity of resistance training, high-intensity interval training, plyometrics, and isometric work that typically occur in some team sports (Foster, Florhaug, Franklin, Gottschall, Hrovatin, Parker, Doleshal, & Dodge, 2001; Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004; Little & Williams, 2007). Furthermore, in team sports characterised by stochastic activities, such as brief and intermittent high-intensity efforts interspersed by longer, lower, intensity efforts, the efficacy of mean HR determined across a whole training session or game has been questioned (Borresen & Lambert, 2008; Impellizzeri, Rampinini, & Marcora, 2005; Stagno, Thatcher, & Van Someren, 2007). Nevertheless, despite limitations, HR monitoring may still be useful for measuring internal aerobic training load (Impellizzeri et al., 2005) and therefore, remains useful to team sports.

Heart rate indices of load

Indices of load are calculated as the product of exercise duration (measure of volume) and exercise intensity. Load indices attempt to quantify training and competition into units of ‘dose’ that equally reflect the volume and intensity of the stimulus. Several methods to calculate such indices based on HR data exit including, training impulse (TRIMP) (Bannister, 1991; Morton, Fitz-Clarke, & Bannister, 1990), Lucia’s TRIMP (Earnest, Jurca, Church, Chicharro, Hoyos, & Lucia, 2004; Impellizzeri et al., 2004; Lucia, Hoyos, Santalla, Earnest, & Chicharro, 2003), and summated heart rate zone methods (Edwards, 1993). Training impulse is most frequently used and is calculated as the product of duration (minutes) and average intensity derived from per cent of $HR_{reserve}$, and a sex-specific correction coefficient to produce scores with arbitrary units (Bannister, 1991). The TRIMP method has been shown to effectively quantify load in endurance events (Padilla, Mujika, Orbananos, & Angulo, 2000; Padilla, Mujika, Orbananos, Santisteban, Angulo, & Goiriena, 2001), but may be less applicable in team sports for many of the same aforementioned limitations with the use of HR monitoring.

To improve load derivates from HR during intermittent activities associated with team sports, summated HR zone scores have been proposed (Edwards, 1993). Duration in each of five HR zones is calculated and multiplied by a factor for each zone and then summated to generate a single score. An assessment of time in different zones may be advantageous over TRIMP because it relies on averaged session HR. However, the use of single zone weightings applied to a range of higher and lower HR’s within that zone may contribute to error (Borresen & Lambert, 2008). A modified version of the summated HR zone method, referred to as Lucia’s TRIMP (Impellizzeri et al., 2004), calculates the time spent in three HR zones corresponding to physiological thresholds such as 1) below the ventilatory threshold, 2) between the ventilatory threshold and respiratory compensation point, and 3) above the respiratory compensation point, multiplied by a coefficient for each zone and summated (Impellizzeri et al., 2004; Impellizzeri et al., 2005; Stagno et al., 2007). Using this approach, soccer players identified as spending more time in higher intensity zones (above onset of blood lactate accumulation-OBLA) demonstrated greater improvements in aerobic capacity than team mates training at lower intensities (Impellizzeri et al., 2005). Similarly, a modified TRIMP designed to weight zones according to the exponential, rather than linear physiological response to increasing exercise intensity (determined using lactate curves) has recently been developed and used in field hockey players (Stagno et al., 2007). Results supported a relationship between modified measures of TRIMP and time spent in high-intensity activities and changes in $\dot{V}O_{2max}$ as well as running velocity at OBLA. These results provide evidence for the potential application of this method for monitoring the training process and training outcome, but require further validation (Borresen & Lambert, 2009).

2.3.3.2 Rating of perceived exertion and indices of load

Rating of perceived exertion (RPE)

Rating of perceived exertion (RPE) is a subjective estimate of exercise intensity based on the assumption that athletes can estimate their own physiological stress with reasonable accuracy. Borg's rating of perceived exertion on a scale of either 6-20 or the more recent modified scale of 1-10 representing very low and very high (maximal) intensities are most widely used (Borg, 1982; Borg, Hasseman, & Lagerstrom, 1987). Perceptions of exertion likely reflect a combination of various physiological factors including HR, lactate, ventilation, $\dot{V}O_2$, blood pH, and body temperature (Groslambert & Mahon, 2006). With increasing exercise intensity, linear increases in physiological variables such as ventilation, HR, and $\dot{V}O_2$ are thought to be paralleled by concomitant increases in RPE. On this basis, HR was originally used as a criterion reference to validate RPE methods (Borg, 1982). Correlation coefficients between HR and RPE in these studies were r=0.85. Other studies have confirmed a strong relationship between RPE and HR during steady-state (Robinson, Robinson, Hume, & Hopkins, 1991; Watt & Grove, 1993) and intermittent exercise (Green, McLester, Crews, Wickwire, Pritchett, & Lomax, 2006). However, a meta-analysis of criterion-related validity of RPE concluded that overall, correlation coefficients are lower than often thought (Chen, Fan, & Moe, 2002). An additional consideration for using RPE to estimate intensity is its validity in relation to differing levels of athletes and stages of development, particularly adolescence. Correlation coefficients between RPE and HR have been reported to be slightly lower for adolescents than adults (Eakin, Finta, Serwer, & Beekman, 1992; Eston & WIlliams, 1986). Since both perceptions of effort and physiological responses to exercise are influenced by a range of factors including psychological factors, the relationship between perception of effort and physiological signs of effort may be more complex, accounting for individual variability physiological and RPE-based estimates of intensity.

Session-RPE

Based on a similar approach used to calculate load indices from HR data, session-RPE method uses RPE data (category ratio scale 1-10) collected within 30 minutes of exercise cessation multiplied by duration in minutes to calculate internal load (Foster, Hector, Welsh, Schrager, Green, & Snyder, 1995; Foster et al., 2001). Possible advantages of RPE indices is the lack of reliance on equipment (such as HR monitors that can fail) and the broad applicability to various exercise modes (outlined above) in which intensity is not well reflected by HR (Foster et al., 2001). Session RPE has therefore, been proposed as a valid and practical method of determining internal load (Herman, Foster, Maher, Mikat, & Porcari, 2006). Session-RPE was originally designed for use in endurance activities and has been shown to correlate with per cent of HR reserve, lactate thresholds, and HR zone based indices in endurance based running (Foster et al., 1995; Foster, 1998).

Given the practical advantages of session-RPE method for estimating internal load and the need for such measures in team sports, the efficacy of using session-RPE in sports during which various types of exercise are performed (intermittent-aerobic and anaerobic, strength, sprint) has recently been investigated. While not all studies have supported the validity of this method for determining load during mixed activity training or competition (Desgorces, Sénégas, Garcia, Decker, & Noirez, 2007), a majority of studies have demonstrated acceptable correlations with alternate methods for determining internal load. Thus the efficacy of session-RPE for team sports (Alexiou & Coutts, 2008; Foster et al., 2001; Impellizzeri et al., 2004) and resistance training (Day, McGuigan, Brice, & Foster, 2004; Singh, Foster, Tod, & Mc Guigan, 2007, Sweet, Foster, McGuigan, & Brice, 2004) has been established. For example, in a study of soccer players, individual correlation coefficients for session-RPE versus TRIMP ranged between r=0.5 and r=0.77, versus summated HR zone method coefficients ranged between r=0.54 and r=0.78, and versus Lucia's TRIMP coefficients ranged between r=0.61 and r=0.85 (Impellizzeri et al., 2004). Similar correlation coefficients have also been reported in other studies comparing session-RPE and HR based indices of load (Borresen & Lambert, 2008). Despite some moderate correlations (r=0.5), using HR based estimates of internal load as the criterion measure, may confound correlation results. Furthermore, it could be argued that since factors other than HR contribute to internal perception of the external load, session-RPE method may in fact be more sensitive (Impellizzeri et al., 2005). Previous studies have shown greater RPE and ventilation responses independent of $\dot{V}O_2$ and HR during continuous versus intermittent running at the same mean velocity (Drust 2000). Greater ventilation can be attributed to respiratory compensation associated with increased lactic metabolism during intermittent running. Given that changes in RPE appeared to reflect these phenomena, it may provide further support for session-RPE efficacy during team sports characterised by intermittent activities.

2.3.4 Section summary

Monitoring load is important for planning and designing training. It is also integral to identifying individual athletes demonstrating signs of maladaptation, and facilitating the titrating of participation loads accordingly. Load monitoring is most successful when it estimates the effect on individual athletes. A variety of methods exist for determining load that include subjective or objective measures of volume and intensity. Additionally, since athletes respond differently to a standardised load, loads can also reflect absolute (external), or relative (internal) demands. Methods frequently used for determining load include external measures of self-reporting and time-motion analyses and internal measures of heart rate and rate of perceived exertion indices. Monitoring load in team sports is a major challenge and since no gold standard method exists, each method needs to be evaluated for validity, reliability and feasibility. Within the limitations of each method, acceptable techniques for monitoring load in team sports exist, providing systematic errors are determined and measurement error is accounted for in the measurements observed.

CHAPTER THREE

METHODOLOGY

3.1 Research design

The three main studies of this thesis were principally prospective, observational cohort studies with an ecological design. Data for the pilot study and three main studies were collected during a total of six rugby seasons. The pilot study was conducted in 2005. Data for the three main studies were collected during three consecutive rugby seasons between 2006 and 2008. Additional data also included in one of the studies were collected during a rugby season in 2003.

This research studied male adolescent (aged 14-18 years) rugby union players. Pilot testing was conducted to establish the reliability, validity and efficacy of the proposed methods and measurement procedures. The methods and instruments that most feasibly focussed on physical loading and responses to loading in adolescent male rugby players were selected. Consequently, biochemical and hormonal markers of training adaptation were not included because of equivocal evidence for their diagnostic potential and additional ethical considerations for collecting such data among adolescents. Subsequent studies used selected instruments and methods to profile and serially monitor adolescent rugby union participation using participants from school, selective school, and state representative teams. Results obtained in each study were used to strengthen subsequent study designs. Research outcomes were used to begin to develop operational definitions for ‘at risk’ adolescent athletes and to establish, in conjunction with Australian Rugby Union, best practice recommendations for the management and development of talented adolescent rugby players. A total of 15 different teams volunteered for this research. A diagrammatical flow chart of the research design is presented in figure 3.1.

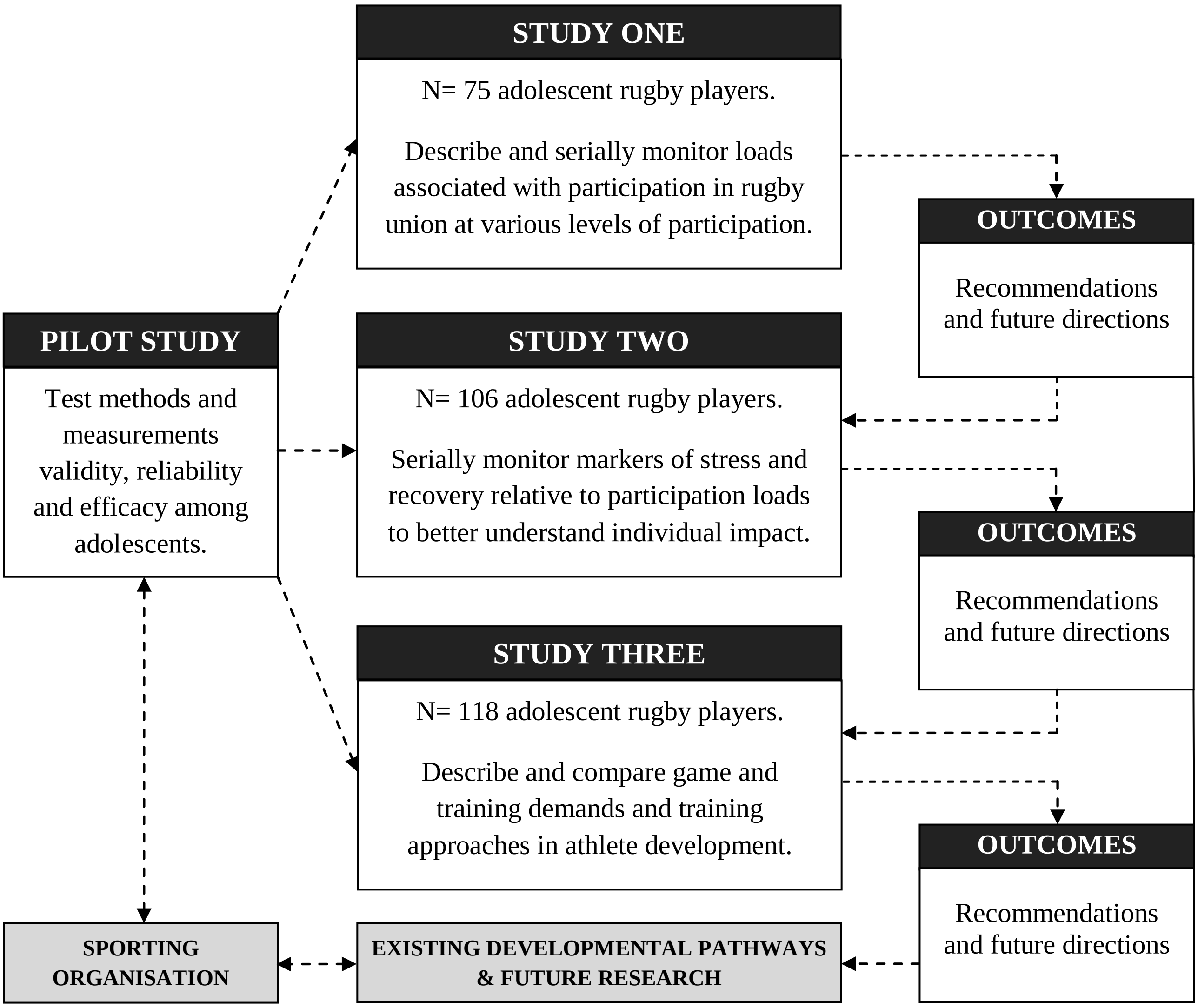

Figure 3.1 Overview of research design

3.2 Ethical approval

Prior to research commencement, ethical approval was obtained from the Human Research Ethics Committee (HREC) at the Australian Catholic University (appendix I).

3.3 Pilot study methodology

Introduction

To assist in better understanding the impact and nature of adolescent participation in rugby union several instruments and testing procedures had to be developed and piloted. Surveys and questionnaires used in subsequent studies to quantify load and psychological indices of load impact were therefore piloted and validated in population-specific participants. In addition, GPS tracking devices used for notational analysis in subsequent studies had not previously been used among adolescent rugby union players and the feasibility and safety of the GPS devices needed to be established.

Participant recruitment

Participants for were recruited on two separate occasions for the pilot study:

i. Fifty male adolescent rugby players from St. Joseph's College, Hunters Hill, Sydney, volunteered to pilot and validate (Face and content validity) the Recovery Stress Questionnaire, training diaries, student surveys, and test the use of GPS tracking devices during rugby training sessions. The school's principal, coaches and players were approached and informed about the project prior to agreeing to participate in the research.

ii. Seventy five male adolescents participating in the 2005 National Under 16's Rugby Championships volunteered to pilot the Recovery Stress Questionnaire (RESTQ) before and during the Championships. Coaches of teams representing Queensland, Western Australia and the Australian Capital Territory volunteered to participate in this phase of the research.

Data collection

Student surveys

To ascertain general descriptive data a student survey was developed. Student surveys were completed by two under 16 teams (N=37) at St. Joseph's College on two occasions during the rugby season. Players completed questionnaires as a group on rugby training days in the presence of a researcher. In a separate section at the end of the survey players recorded any comments or questions they had about the questions asked in the survey. Face and content validity were established by consulting exercise science and coaching specialists during the development of the survey and through the use of existing literature when deciding what types of information would be relevant to this study.

Training diaries

Training diaries which included weekly questions about stress, injury and illness were administered to two teams (N=37) from St. Joseph's College over four weeks of a rugby season. To familiarise the participants with training diary completions, week one was completed at the end of a rugby training session in the presence of a researcher. Week's two to four were taken home and completed in the participant's own time. Feedback from the diary evaluation forms and a poor diary entry compliance rate led to the decision to have participant's complete diaries at end of training sessions in the presence of researchers in the remainder of the pilot and subsequent studies. Training diaries, including injury and illness questions were developed in consultation with coaching staff.

Recovery Stress Questionnaire

The Recovery Stress Questionnaire (RESTQ) (Kellmann & Kallus, 2001a) was used to monitor psychological markers of stress and recovery. While this questionnaire has established validity and reliability among adults and older adolescents (Kellmann, Kallus, Steinacker, & Lormes, 1997) it's use with younger than previously tested participants required that it be piloted. The RESTQ was therefore administered to three teams (N=60) during a weeklong National Under 16's Rugby Championships in 2005. Questionnaires were completed on two occasions, the day before Championships commenced and on the second last day of competition. On both occasions the questionnaire was administered by the team manager who had received instructions about administering the questionnaire. Recovery Stress Questionnaires were also piloted among St. Joseph's College rugby players (N=37). Participant feedback resulted in changes being made to four questions in the original RESTQ-Sport. Questions were modified following participants expressing confusion about the wording used or the appropriateness of the circumstance described. Modifications did not in any way alter the original meaning of the questions. Question 16: *'I was tired from work'* was changed to *'I was tired from school'*. Question 25: *'I was dead tired after work'* was changed to *'I was dead tired after school'*. Question 31: *'I was lethargic'* was changed to *'I was lazy and had no energy'*. Question 47: *'I felt content'* was changed to *'I felt satisfied'*.

GPS tracking devices

To our knowledge GPS devices had not previously been used in rugby union. Rugby union officials and coaches at the Australian Rugby Union expressed concern about GPS units being worn by adolescent players during rugby training sessions because of the frequency and nature of contact experienced during training. GPS units therefore needed to be trailed to determine player risk before they could be used more extensively in future data collection phases. Initially, two players at a time from St. Joseph's College wore GPS units during training sessions. For eight rugby training sessions, players rotated wearing the GPS units during training. For the first four weeks only backs wore the units since they are usually involved in fewer contact phases than forwards during training. After establishing that GPS units pose relatively low risk for injury, their use was expanded to also include forwards. Coaches and Australian Rugby Union officials agreed that the GPS devices represented only a minor risk to player safety during all forms of training, but safety concerns remained about their use during rugby games which in addition to International Rugby Board laws, precluded GPS data collection during competitive games.

3.4 General methodology (study one – three)

3.4.1 Participant recruitment

Participants were recruited from various levels of rugby involvement that included, school, selective school, and state representative rugby. Recruitment was mediated by strong support from Australian Rugby Union officials who used contacts and industry partnerships to help source willing and cooperative research participants. Once potential coaches and teams had been identified and informed of the research (appendix II), parents / guardians were informed about the aims and basic procedures of the research via an information letter (appendix III). Written consent and, or, assent where appropriate, were obtained from athletes and parents / guardians (appendix IV). Parents / guardians, players, and coaches were aware that they were not obligated to volunteer to participate and that withdrawal at any stage was permitted without consequence to their son’s rugby participation or team selection. Coaches and teams voluntarily participated in the research project with no coercion from the Australian Rugby Union.

3.4.1.1 Inclusion criteria

To be included in the studies, participants had to be:

i. male, aged 14 – 18 years

ii. participating in the game of rugby union including training and matches at time of recruitment

iii. free of injury to the extent that they were still able to play and train in the month prior to recruitment

3.4.2 Questionnaires

3.4.2.1 Student survey

A student survey was designed for the purpose of obtaining descriptive data (appendix V). The final version of the student survey was used to obtain four types of information that were regarded as being important; (1) sociodemographics, (2) current and previous rugby participation, (3) understanding of recovery and current recovery practices, and (4) nutritional practices.

3.4.2.2 Training diary

A weekly training diary was developed to quantify weekly rugby training load as well as the relative load of all other sport and physical activity (appendix VI). The training diary was designed to measure three key points about all types of physical activity (1) activity type, (2) activity duration, and (3) activity intensity. Players also completed a section on weekly injury and illness that included questions about the extent to which normal training and activities had been affected. Players were instructed how to complete training diaries and provided 2 weeks of familiarisation data before data were retained for analysis. Training diaries were completed by participants at the end of the last training session of the week. Researchers were present when training diaries were completed and players were instructed to record all sports and physical activities lasting 15 minutes or longer. In addition to recording the nature and duration of activities completed, ratings of perceived exertion on the Borg category ratio scale 1-10 (Borg et al., 1987) were also entered into the diary for all activities. Researchers used prompts about significant days (such as game days, training days and physical education) to assist participants recall the past week's activities. In an attempt to control quality, diary entries were regularly checked by coaching staff.

3.4.2.3 Recovery Stress Questionnaire (RESTQ-Sport)

The Recovery-Stress Questionnaire consists of 77 items (76 plus one warm-up item) that assesses the frequency of stress-related and recovery-related activities experienced in the past three days and nights. The questionnaire has a total of 19 scales including 12 scales of general stress and recovery and seven sport-specific scales (Kellmann & Kallus, 2001a). Seven scales assess general subjective strain including; general stress, emotional stress, social stress, conflicts / pressure, fatigue, lack of energy and somatic complaints. Recovery scales include; success, social relaxation, somatic relaxation, general well-being and sleep quality. The seven sport-specific scales include stress scales; fitness / injury, emotional exhaustion, and disturbed breaks and recovery scales; being in shape, burnout / personal accomplishment, self-regulation, and self-efficacy (Kellmann & Kallus, 2001a). Participants responded to the items indicating how often they participated in various activities using a Likert scale from 0 (never) to 6 (always). High scores in the stress-related activities indicate high subjective stress while high scores in the recovery-related scales suggest good recovery patterns.

3.4.3 Time- motion analysis

3.4.3.1 Global positioning system (GPS)

Global Positioning Satellite (GPS) technology was used to quantify players' rugby training loads and describe training practices. Recent developments in GPS technology have seen the release of commercially available GPS tracking units small and accurate enough for sporting applications. A total of six SPI 10 GPS units were used to capture training data (GPSports Systems Pty Ltd 2003, Canberra, Australia). The SPI 10 model has a sampling frequency of 1 Hz. The reliability and validity of this system have previously been outlined. While newer models with higher sampling rates exist, at the time of data collection commencement the SPI 10 GPS units were the most readily available GPS system in Australia. The GPS tracking units were strapped between player's shoulder blades using a specifically designed soft neoprene pouch. Tracking units were only worn during training because of safety concerns given the size and placement (upper thoracic spine area) of the units worn and the more full contact nature of rugby games. Heart rate data were also obtained by the GPS devices using polar heart rate straps. A maximum of six devices were randomly assigned to players during the data collection period. All players wore a GPS device on at least one occasion to enable movement data collection for all field positions.

3.4.3.2 Computer-based tracking (CBT)

Time-motion analysis software (Trak Performance, Sports Tec Pty Ltd, Australia) was applied to video footage collected during rugby games across several rugby seasons. Trak Performance software permits the analysis of movements of each participant recorded. The software allows researchers to simulate real time movements of the participants by observing video footage and ‘tracking’ player’s locomotive movements. Tracking occurs on a scaled version of the playing field superimposed on a drawing tablet attached to a computer. Video footage used for analysis required spatial references such as field markings to improve analysis accuracy. An elevated viewing platform was selected to adequately capture playing fields and participants. Timing gates (Swift Performance, Lismore, Australia) were used to establish appropriate speed zones for the participants’ locomotor movements. Results were entered into the Trak Performance program to set population-specific speed zones for stationary (0-1 $km.h^{-1}$), walk (1-7 $km.h^{-1}$), jog (7-12 $km.h^{-1}$), stride (12-21 $km.h^{-1}$), and sprint (21+ $km.h^{-1}$). Speed zone settings were used to program GPS and CBT software. Two experienced researchers analysed all game video footage. Inter and intra-rater reliability for

CBT was established by two repeated analyses of the same game video footage. A 6% coefficient of variation for distance measures was achieved (Hopkins, 2000).

3.4.4 Anthropometric data

Anthropometric measures of height and weight were recorded. Body mass was measured using a digital scale (Wedderburn, UWBW150) accurate to 0.01 kg and stretch stature (Norton & Olds, 1996) was measured using a stadiometer. Anthropometric data were collected in accordance with the guidelines outlined by Norton and Olds for ISAK standards.

3.5 GPS and CBT method agreement study

3.5.1 Introduction

To compare game and training demands among adolescent rugby players, Computer Based Tracking (Trak Performance, Sports Tec Pty Ltd) and Global Positioning Satellite (SPI 10, GPSports Systems Pty Ltd 2003) devices were used. Methodological constraints precluded the use of a single time-motion analysis technique to determine player movement patterns during games and training. Specifically, at the time of data collection, the use of GPS devices during games was not permitted by rugby's governing body because of concerns for player safety. Additionally, CBT methods require video footage captured from an elevated vantage point for accurate analysis, while this was possible for games, training sessions were rarely completed on fields that had access to vantage points. Since no previous studies had investigated the efficacy of comparing GPS and CBT data for high-intensity, intermittent activities a method comparison study was designed to determine agreement between these two time-motion analysis techniques.

3.5.2 Method

Two moderately trained male participants (age 20 years) each completed 30 laps of a circuit designed to simulate typical team sports movement patterns (based on previous team-sport notational analyses). The circuit design is presented in figure 3.2. The circuit was clearly marked out on a level playing field using line marking paint and cones. The total distance covered for each completion of the circuit was 144 meters. Each participant therefore covered a total distance of 4320 meters. Participants moved through the circuit in three different ways to produce varied sprint, jog and walk movement patterns, 1) participants sprinted up field and walked across field, 2) participants jogged the entire circuit, and 3) participants jogged up field and sprinted across field. Participants were also stationary for portions of the circuit test. Participants were allowed two minutes for each completion of the circuit before having to commence the next lap. Complete laps were always performed in less than two minutes, with the remaining time spent in stationary recovery.

GPS units were strapped onto participants and data sampling commenced several minutes before the circuit test. A video camera (Sony DCR-HC36E) mounted on a tripod was set up on a vantage point overlooking the marked out circuit. Video footage was then used for CBT (using Trak Performance) of each participant performing the circuit test. GPS and CBT generated time-motion data of total distance covered, percent time and distance covered walking (1-7 $km.h^{-1}$), jogging (7-14 $km.h^{-1}$), high intensity running (14^{+} $km.h^{-1}$), time spent stationary (0-1 $km.h^{-1}$), and velocity of sprints performed. Actual distance travelled was measured using a tape measure and 10 meter sprint velocity was measured using timing gates. The level of agreement between GPS and CBT time-motion analyses methods was estimated using 95% limits of agreement (Bland & Douglass, 1999; Cooper, Baker, Tong, Roberts, & Hanford, 2005). The predictability of participants moving through the circuit may have biased the measurements determined by CBT and is therefore acknowledged as a limitation.

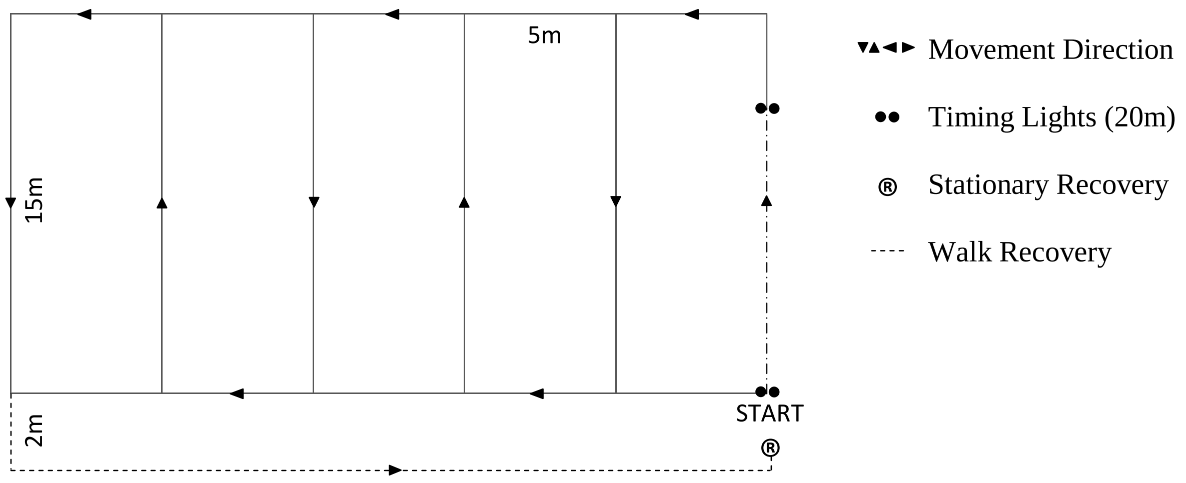

Figure 3.2 Circuit test used to simulate typical team sport player movement patterns

3.5.3 Results

Table 3.1 GPS and CBT time-motion analyses results for circuit test (data are means for two participants measured using both GPS and CBT).

	GPS	CBT
Total Distance (m)	3973	4410
Percent Time Stationary (%)	39.9	40.8
Walk Distance (m)	1455	1543
Jog Distance (m)	1881	2071
High Intensity Run Distance (m)	567	768
Average 20m Sprint Velocity (km.h^{-1})*	17.3	18.9

**Average 20 m sprint velocity determined using timing gates = 17.6 km.h^{-1}*

GPS and CBT velocity data over each lap were compared using 95% limits of agreement (LoA), calculated as ± 1.96 × standard deviation of the residual errors (Bland & Douglas, 1999; Cooper et al., 2005). Calculations of LoA were determined from data for time spent stationary, walking, jogging and high intensity running. Mean lap times measured using CBT and GPS, respectively were; stationary 48.9 and 47.6 s (LoA ± 5.4s), walk 38.6 and 41.8 s (LoA ± 8.9s), jog 27.2 and 25.9 s (LoA ± 8.9s), and high intensity running 5.3 and 5.2 s (LoA ± 2.2s).

3.6 General statistical approach

All continuous variables were tested for normal distribution using seven criteria. Variables were considered normally distributed if; there was less than 10% difference between mean and median values, the doubled standard deviation was less than the mean, analysis of skewness and kurtosis were within the range of -1.0 to 1.0, skewness and kurtosis scores divided by their corresponding standard errors had values less than 1.96, and Kolmogorov-Smirnov tests for normal distribution with Lilliefors' significance correction generated p values ≥ 0.05 (Peat & Barton, 2005). Data were treated as non-normally distributed if the doubled standard deviation was greater than the mean, there was a greater than 10% difference between the mean and median and one or more of the other criteria were not met.

Following tests for normality, descriptive data were presented in medians, means, ranges, and standard deviations. When appropriate, poorly distributed continuous data were log transformed. Normally distributed data were presented in means ± standard deviations and treated with parametric analyses. Non-normally distributed data were presented in medians and interquartile ranges and treated with non-parametric analyses. Paired samples t-tests, independent t-tests and Mann-Whitney U tests were performed on dependent variables for comparisons between independent variables. Pearson bivariate correlations were performed to determine if regression analyses for dependent variables could be justified. One-way ANOVA analyses were used to compare differences where there were three or more groups and unadjusted Bonferroni post hoc analyses were used to locate and assess the magnitude of group differences. When there were imbalanced numbers between correlated groups, mixed model ANOVA's were used with participants as the random effect. In some instances, to limit inflation of type 1 errors, a Holm's correction was applied to related dependent variables by progressively adjusting the critical alpha level based on the number of comparisons made. Statistical package SPSS version 14.0-17.0 was used and significance was accepted at an alpha level of $p<0.05$.

CHAPTER FOUR

STUDY ONE:

DEFINING THE VOLUME AND INTENSITY OF SPORT PARTICIPATION IN ADOLESCENT RUGBY UNION PLAYERS

DEFINING THE VOLUME AND INTENSITY OF SPORT PARTICIPATION IN ADOLESCENT RUGBY UNION PLAYERS

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Research Type: Original Investigation

Running Title: Defining Participation in Junior Rugby

Key Words: Notational analysis, global positioning satellite, training diaries, training load, adolescent.

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4.1 Abstract

Investigating adolescent training loads may assist in understanding optimum training adaptations. Therefore, GPS tracking devices and training diaries were used to quantify weekly sport and other physical activity demands placed on adolescent rugby union players and profile typical rugby training sessions. Participants were 75 males aged 14 to 18 years who were recruited from rugby teams representing three levels of rugby participation (1) school boy, (2) national representative, and (3) a selective sports school talent squad. School boy players covered a distance of (mean ± standard deviation) 3511 ± 836 m, representative squad players 3576 ± 956 m, and talent squad players 2208 ± 637 m per rugby training session. The representative squad recorded the highest weekly duration of sport and physical activity (515 ± 222 min/week) followed by the talent squad (421 ± 211 min/week) and school boy group (370 ± 135 min/week). Profiles of individual players identified as group outliers showed participation in up to three games and up to eleven training sessions per week with twice the weekly load of the team averages. Optimum participation and performance of adolescent rugby union players may be compromised by many high load, high impact training sessions and games, and commitments to other sports and physical activities. An improved understanding of monitoring and quantifying load in adolescent athletes is needed to facilitate best practice advice for player management and training prescription.

4.2 Introduction

To facilitate optimal participation and performance in adolescent sport, every effort should be made to ensure appropriate training prescription and player management practices. For adolescents, the training and game demands of sports are becoming increasingly more adult like (Hollander et al., 1995). With a 'more is better' approach in some training programs, detrimental effects on health, performance and participation are possible outcomes for adolescents (Dalton, 1992; Hagglund, Walden, & Ekstrand, 2005; McKenzie, 1999; Polman & Houlahan, 2004). Consequently, a need exists to monitor young players' participation in sports to determine the most appropriate workloads and ensure future participation and performance are not compromised (Smith, 2003b). In the absence of accepted criteria for optimal participation and performance in rugby, the focus of this paper will be on quantifying selected loading in adolescent players during training and games.

Adolescents are worthy of special consideration because some may be participating in various team and individual sports with high physical demands. Adolescents in Australia can participate in a number of sports without individual coaches being aware of the physical demands imposed by participation elsewhere. In addition, adolescents can compete and train within the same sport with several teams representing different levels of competition such as community clubs, schools, and representative and selective talent squads. Subsequently, the physical demands associated with popular sports such as rugby union are currently poorly documented and no evidence-based strategies exist to monitor participation loads.

Defining volume and intensity in team sports such as rugby union is challenging. However, advances in notational analysis technology such as global positioning satellite systems (GPS) permit an acceptable assessment of previously relatively imprecise estimates of training speeds, distances and intermittent movement intensities. Notational analyses of elite players in most sports are increasingly reported (Bangsbo, Norregaard, & Thorso, 1991; Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004a; Duthie, Pyne, & Hooper, 2003), but few reports are available for aspiring elite adolescents. Therefore, the purpose of this study was to use notational analyses and self-reporting to define the current level of physical demands during a typical rugby season including training, competitive games and all other sport and physical activities in adolescent male rugby union players. An additional purpose was to define the variation in activity patterns for varying levels of participation.

4.3 Methods

Participants

Following ethical approval from the University's Human Research Ethics Committee, 75 male rugby union players aged 14 to 18 years were recruited for the study. In addition to parental consent, players had to be free of injury and actively engaged in rugby training at the time of recruitment. Players were recruited from rugby teams representing three levels of rugby participation (1) school boy, (2) national representative, and (3) a selective sports school's high performance talent squad. Staff at the Australian Rugby Union assisted with recruitment via facilitated links with the schools and teams used in this study. Players and coaches were invited to participate in the project and were free to choose to not participate.

Research design

The volume and intensity of participation in rugby as well as participation in other sport and physical activity were estimated using notational analysis technology and data recorded in weekly training diaries. Measures were taken twice a week for 12 weeks representing a full school-boy competitive rugby season, for six weeks leading into the end of the representative rugby season, and for 10 weeks leading into the end of the selective high-performance squad rugby season. Global positioning satellite (GPS) technology and heart rate monitoring were used to track the volume and intensity of rugby training sessions. In addition, detailed weekly training diaries were completed to record the amount and subjective rating of the intensities of sport and physical activity in which players participated outside of rugby training.

Procedures

Anthropometric and descriptive data

Anthropometric measures of height and weight were recorded. Body mass was measured using a digital scale (Wedderburn, UWBW150) accurate to 0.01 kg and stretch stature (Norton & Olds, 1996) was measured using a stadiometer. Descriptive data about players' history of participation in rugby were obtained using a player survey that had previously been piloted in an aged and sport-matched population. Participants' descriptive data are presented in means and standard deviations in Table 1.

Table 4.1 Descriptive data (mean ± SD) from three levels of male adolescent rugby union players.

	School boy (N = 29)	**Representative squad (N = 27)**	**Talent squad (N = 18)**
Age (yr)	15.2 ± 0.6	15.6 ± 0.7	16.4 ± 1.5
Height (cm)	177 ± 7	180 ± 6	179 ± 7
Weight (kg)	72.7 ± 10.2	87.3 ± 12.9*	93.3 ± 13.1*
Years playing rugby	5.2 ± 3.0**	7.4 ± 3.1	5.1 ± 2.5

*Significantly different from school boy, $P < 0.001$.

**Significantly different from representative squad, $P = 0.027$

Training diaries

Training diaries were selected to assist in volume estimates since they represent the most pragmatic means of longitudinally assessing training despite acknowledged limitations of a high burden on participants and problems with compliance (Bratteby, Sandhagen, Fan, & Samuelson, 1997; Hopkins, 1991). At the end of the last training session for the week, players completed a detailed seven day training diary. Diaries were completed in the presence of researchers. Players were instructed to record all sports and physical activities lasting 15 minutes or longer. In addition to recording the nature and duration of activities completed, ratings of perceived intensity on the 1-10 Borg Rating of Perceived Exertion (RPE) Scale (Borg, 1982) were also entered into the diary. Researchers used prompts about significant days (such as game days, training days and physical education) to assist participants recall the past week's activities. Diary entries were regularly verified by coaches to ensure quality of at least some of the subjective data. Team coaches and coaching staff at the Australian Rugby Union confirmed that reported weekly training volumes approximated expected values. To assist in the need to exclude atypical training weeks from the data analysis, players completed a section on weekly injury and illness which included questions about the extent to which normal training and activities had been affected.

Notational analysis

Analyses of players' rugby training volume and intensity were achieved through the use of GPS tracking devices (SPI10, GPSports Systems Pty Ltd 2003, Canberra, Australia) and heart rate monitors. When worn by players, the GPS device communicated with earth orbiting satellites to triangulate location, yielding time, distance and velocity data (Larsson, 2003). Heart rate data were also obtained by the GPS devices. The SPI10 GPS devices were worn between players' shoulder blades in the upper thoracic spine region. The GPS devices were worn during two training sessions a week for the duration of the study. A maximum of six devices were randomly assigned to players during the data collection period. Almost all players wore a GPS device on at least one occasion which enabled movement data collection for all field positions. The SPI10 GPS devices recently showed acceptable validity for measuring distance (Edgecomb & Norton, 2006).

Statistical analysis

Following tests for normality, descriptive data were presented in medians, means and standard deviations. Poorly distributed continuous data were log transformed for analytical purposes. One-way ANOVA analyses were used to compare differences among the three groups and unadjusted Bonferroni post hoc analyses were used to locate and assess the magnitude of group differences. Significance was accepted at an alpha level of $P < 0.05$ for analyses.

4.4 Results

Profile of rugby training sessions

Typical rugby training sessions were profiled using data derived from GPS analyses. Duration, distance, and measures of intensity were recorded from training sessions. Table 2 presents the total number of training hours tracked as well as the number of times the GPS and heart rate devices were worn throughout the rugby season (test frequency). Session duration was the longest for the representative squad, followed by the school boy program, with talent squad sessions shortest in duration. Since mean session duration differed between groups, mean distance covered per one hour of training was calculated to allow for group comparisons (Table 2). Mean distance covered per hour was compared using one-way ANOVA with the results showing a significant difference. [F (2, 158) = 19.99, P = < 0.001]. The school boy program recorded the highest distance per hour. Unadjusted Bonferroni post hoc analysis showed differences between school boy squads and the representative (P = < 0.001) and talent squads (P = < 0.001), and no differences between the representative and talent squads (P = 1.000).

Table 4.2 Rugby training and GPS analyses descriptive data.

	School boy (N=35)	**Representative squad (N=19)**	**Talented squad (N=20)**
Hours analysed (h/m)	104:54	37:45	43:48
Test frequency	90	25	46
Mean session duration (h/m)	1:12 ± 0:18	1:33 ± 0:19	0:58 ± 0:12
Distance per hour of training (km/h)	3.0 ± 0.76	2.4 ± 0.85*	2.3 ± 0.42*

*Significantly different from school boy, P < 0.001.

The mean distance covered by players during rugby training sessions is presented in Figure 1. School boy players covered (mean ± SD) 3511 ± 836 m, representative squad players covered 3576 ± 956 m, and talent squad players covered 2208 ± 637 m. One-way ANOVA results showed differences between groups in average distance covered per session [F (2, 158) = 43.96, P = < 0.001]. Unadjusted Bonferroni post hoc analysis showed the mean distance covered in talent squad sessions was less than the representative squad sessions (P = < 0.001) and school boy sessions (P = < 0.001). Mean distance covered during sessions was not different between the representative squad and school boy players (P = 1.000). The frequency and average duration of locomotor efforts occurring at speeds greater than 14 km/h (termed high intensity efforts) were determined. No group differences were found for the average duration of high intensity efforts (P = 0.147). School boy players performed high intensity efforts lasting an average 2.6 s (range: 1.3-5.9), representative squad players 2.6 s (1.3-4.6), and talent squad players 2.3 s (1-6.3). Frequency of high intensity efforts was different among the groups using one-way ANOVA [F (2, 158) = 5.061, P = 0.007]. The number of high intensity efforts recorded per one hour of training was 28.2 (5-88) for school boy players, 23.3 (2-61) for representative squad players and 20.0 (4-52) for talent squad players. Unadjusted Bonferroni post hoc analysis indicated differences between school and talent squad players for frequency of high intensity efforts (P = 0.012).

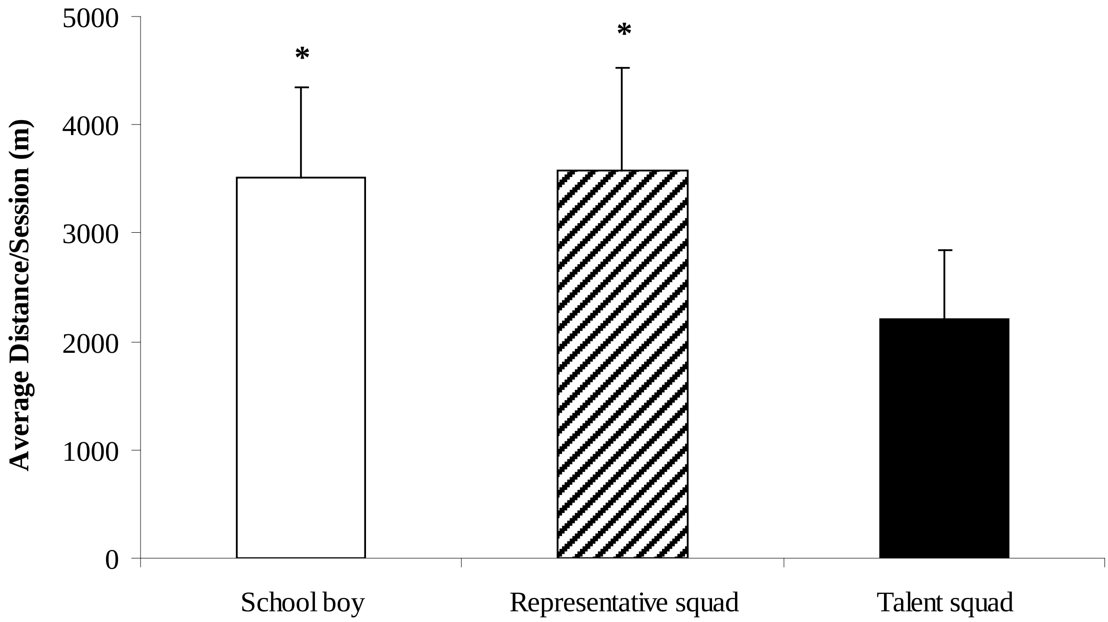
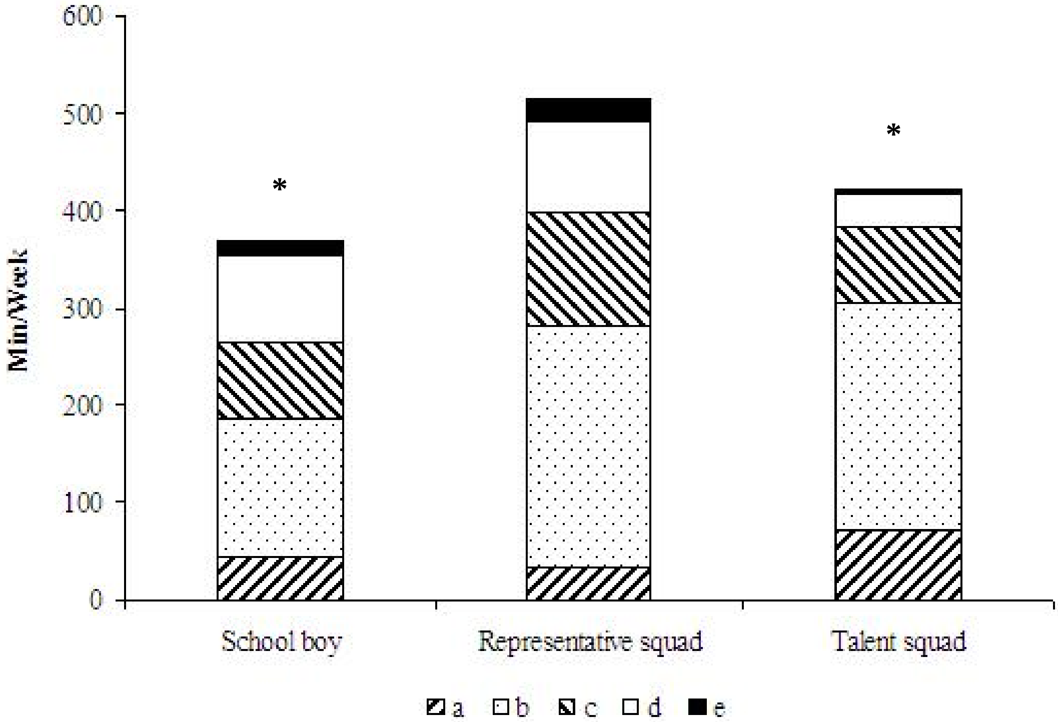


Figure 4.1 Mean distance in meters per session for three levels of participation assayed using repeated GPS analyses across the rugby season. *Significantly different from Talent squad, P < 0.001.

Results from an ANOVA on maximal and mean heart rate data collected during rugby sessions found no differences between groups for mean heart rate (P = 0.290). Differences between groups were found for maximal heart rate [F (2, 148) = 8.51, P = < 0 .001]. Maximal and mean heart rate scores were 200 ± 13 and 141 ± 12 $b.min^{-1}$ for school boy, 196 ± 12 and 136 ± 17 $b.min^{-1}$ for the representative squad, and 189 ± 15 and 140 ± 17 $b.min^{-1}$ for the talent squad. As an additional descriptor of training intensity percent time spent above 85% of age predicted heart rate maximum was also calculated. Group differences were found using one-way ANOVA [$F(2, 135) = 4.664$, $P = 0.011$]. The percent time spent above 85% of age predicted heart rate maximum was 22.6% (0-94.8) for school boy players, 16.5% (0.1-58.8) for representative squad players and 18% (0-58.2) for talent squad players with differences between school boy and representative squad players significant ($P = 0.017$).

Profile of weekly training

Participants' typical weekly training, including the duration, intensity and type of all sports and physical activities were profiled using training diary data. Weekly duration in minutes per week and a breakdown of specific activities that comprise the weekly duration for each of the three groups are presented in Figure 2. Results of the one-way ANOVA analyses identified group differences [$F(2, 392) = 21.02$, $P = < 0.001$] with the representative squad recording the highest weekly duration (515 ± 222 min/week) followed by the talent squad (421 ± 211 min/week) and school boy group (370 ± 135 min/week). Unadjusted Bonferroni post hoc analysis found that the weekly duration of activity of representative squad players' differed significantly from the talent squad players' ($P = 0.001$) and the school boy group ($P = < 0.001$). In the school boy group, 12% of weekly duration of all activity was rugby games, 38% rugby training, 22% rugby-related activities, 24% school and other organised sport and physical activities, and 4% was spent in other recreation assumed to occur above resting energy expenditure. In the representative squad, rugby games accounted for 7% of weekly activity, rugby training 48%, rugby-related activities 22%, school and other organised sport and physical activities 18%, and recreation activities accounted for the remaining 5%. In the talent squad, rugby games contributed 17% of reported weekly activity, rugby training 56%, rugby-related activities 18%, school and other organised sport and physical activities 8%, and the remaining 1% was assigned to recreational activities. Within acknowledged limitations and for the purpose of comparisons, the product of players' weekly total duration and RPE scores was termed weekly load (Foster, 1998). Group differences for players' weekly load were found again using one-way ANOVA [$F(2, 368) = 27.75$, $P = < 0.001$]. The representative squad had the highest weekly load of 3645 ± 1588, followed by the talent squad with a weekly load of 2907 ± 1586. The school boy squad had the lowest weekly load of 2372 ± 1009. Unadjusted Bonferroni post hoc analysis showed significant differences between the representative squad and the talent squad ($P = < 0.001$), the representative squad and the school boy group ($P = < 0.001$), and the school boy group and the talent squad ($P = 0.005$).



[a] Rugby game, [b] rugby training, [c] rugby related (included weight training, rugby specific skills or fitness sessions, touch rugby, rugby league training and games), [d] school/other organised (included school sports, physical education, and all other organised sports and physical activities), [e] recreational (included general non-specific fitness, and recreational sports and physical activity).

Figure 4.2 Mean total weekly duration and a breakdown of weekly activities in minutes/week reported in training diaries. *Significantly different from representative squad, $P < 0.001$.

An estimate of the intensity of the specific activities that comprised the weekly duration for each of the three groups was provided by RPE data. Average recorded RPE scores for the school boy group were 8.6 ± 1.6 for rugby games, 6.4 ± 1.7 for rugby training, 5.9 ± 1.8 for rugby-related activities, 5.2 ± 1.8 for school and other organised sport and physical activities, and 6.2 ± 1.7 for recreational activities. For the representative squad RPE scores were 8.3 ± 1.7 for rugby games, 6.8 ± 1.7 for rugby training, 7.2 ± 1.8 for rugby-related activities, 5.7 ± 2.2 for school and other organised sport and physical activities, and 6.8 ± 1.7 for recreational activities. In the talent squad RPE scores were 8.1 ± 1.4 for rugby games, 6.7 ± 1.8 for rugby training, 6.9 ± 1.6 for rugby-related activities, 4.7 ± 2.3 for school and other organised sport and physical activities, and 5.1 ± 2.5 for recreational activities. One-way ANOVA found group differences in recorded RPE for rugby training [$F (2, 927) = 3.83$, $P = 0.022$], for rugby-related activities [$F (2, 670) = 38.53$, $P = < 0.001$], for school and other organised sport and physical activities [$F (2, 446) = 5.07$, $P = 0.007$], and for recreational activities [$F (2,104) = 3.74$, $P = 0.027$]. Unadjusted Bonferroni post hoc analysis showed differences between the school boy group and the representative squad for rugby training ($P = 0.028$), the school boy group and the representative and talent squad for rugby-related activities ($P = < 0.001$), the representative and talent squad for school and other organised sport and physical activities ($P = 0.007$), and the representative and talent squad for recreational activities ($P = 0.039$). Rugby games consistently rated highest for RPE for all three groups.

Case studies

The player from each of the three groups who recorded the greatest weekly duration (min/week) was selected as a case study. Figure 3 presents the reported mean weekly duration of sports and physical activities for teams and individual case studies. The case study athlete from the school boy group reported a sports and physical activity duration of 730 ± 49 min/week. In the representative squad the case study athlete reported 792 ± 226 min/week. In the talent squad the case study athlete reported 804 ± 335 min/week. The case study athlete from the school boy group had a mean weekly load (duration × RPE) of 5468 ± 470. The case study athlete from the representative squad reported a mean weekly load of 4892 ± 1720. The case study athlete from the talent squad had a mean weekly load of 5699 ± 3122. The case study from the school boy group had a maximum weekly duration of 890 min/week with a peak weekly load of 5810. The case study from the representative squad had a maximum weekly duration of 1020 min/week and a peak weekly load of 7020. The case study from the talent squad had a maximum weekly duration of 1591 min/week with a peak weekly load of 13185.

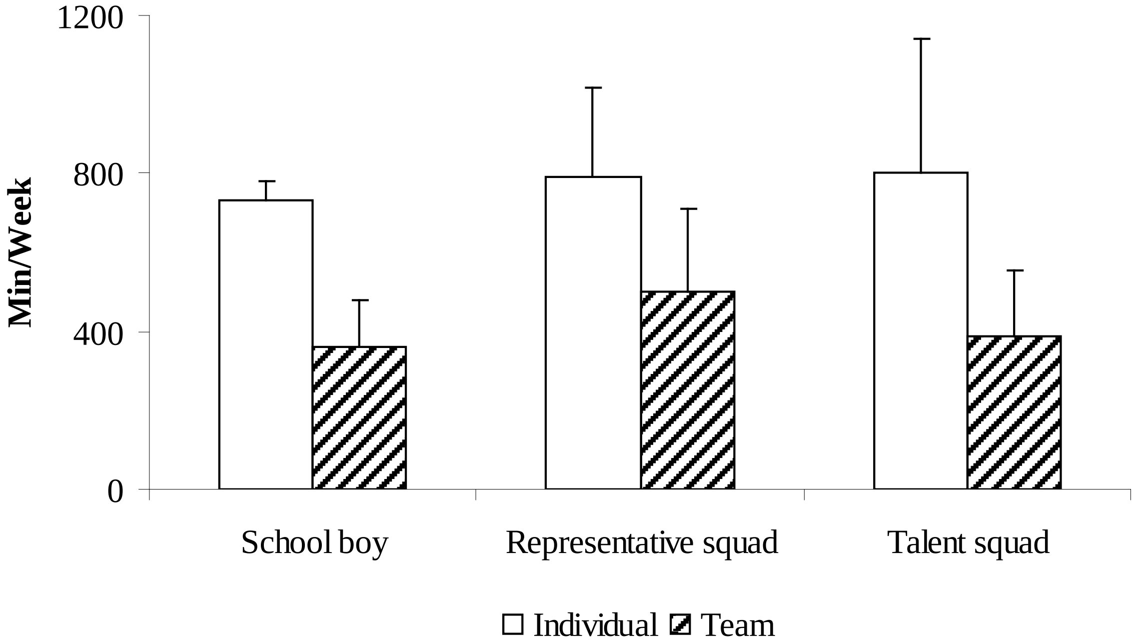


Figure 4.3 Individual vs. rest of team average weekly duration of sport and physical activity in minutes per week.

A breakdown of the activities each case study reported doing to comprise their weekly duration is presented in table 3. In addition to the median frequency of activities reported by the case studies, the maximum number of activities recorded per week is also presented. The school boy case study reported a median participation rate of 12 sessions a week with rugby and rugby related sessions comprising eight of the 12 sessions. In the representative squad the case study athlete recorded a median of 8 sessions a week with 4 rugby and rugby related sessions. The talent squad case study reported a median participating rate of 12 sessions a week with a median of 10 rugby and rugby related sessions.

Table 4.3 Breakdown of case study's weekly sports and physical activities.

	School boy		Representative		Talent	
	Median	**Max.**	**Median**	**Max.**	**Median**	**Max.**
Rugby game	2	3	1	3	1	2
Rugby training	2	3	3	4	6	11
Rugby related [a]	4	6	0	2	3	4
School/other organised [b]	4	6	4	7	0	1
Recreational [c]	0	1	0	0	1	2

[a] Included weight training, rugby specific skills or fitness sessions, touch rugby, rugby league training and games. [b] Included school sports, physical education, and all other organised sports and physical activities. [c] Included general non-specific fitness, and recreational sports and physical activity.

4.5 Discussion

Descriptions of the physical demands placed on adolescent rugby union players are lacking. This study describes young rugby union players' typical weekly loads and profiles observations of rugby training sessions. Discernable and significant group differences for weekly loads as well as distance, duration and intensity of training sessions highlight the need and benefit of monitoring players across varying levels of participation. Major findings on training profiles showed school boys travelled further by at least half a kilometre per one hour of training than the players in the other two groups. Differences in the distance covered per training session were also found with players in the talent squad travelling approximately one kilometre less in rugby training sessions than players in the other two groups. School boy players also performed more high intensity locomotor efforts per one hour of training compared with the talent squad players and spent a greater percent of training time at intensities above 85% of age predicted heart rate max compared with representative squad players. Using a subjective definition of talent, these findings indicate that the least talented group (school boy group) recorded the highest training distance per hour at a relatively higher intensity while the most talented group (talent squad) recorded the least distance per training session at relatively lower intensities. It is possible the results reflect differing coaching techniques and varied distributions of attention to skill, physical and tactical components of training and to a lesser degree, variations in the periodised training year. These findings warrant further investigation to explain the likely cause of variations in training and any subsequent effect on performance.

Profiles of weekly training found that mean weekly duration of sport and physical activity varied considerably among groups while the distribution of total weekly activity categories was similar. For all three groups, when combining rugby training, rugby games and other rugby related activities, results showed that a majority of weekly activity time per week was spent involved in rugby. These results suggest that most of the players' weekly physical activities involved high impact, high intensity type activities. For weekly activity duration, the school boy group averaged the lowest with approximately 6 hours per week, followed by the selected talent squad with approximately 7 hours per week. The representative squad recorded the highest duration with approximately 8.5 hours of activity per week. Although every effort was made to match the periodisation phases between the research groups, matching groups was difficult because rugby participation was a year-round activity for some of the players in this research. Differences between periodisation programs might therefore, explain the higher hours per week of activity in the representative squad than the talent squad and school boy group. An alternative explanation might be that as players' qualify and progress to more elite teams such as the talent squad, coaches are more able to limit players' activity choices. Coaches of elite players often advise players not to participate in activities that increase weekly training duration for little perceived benefit. In contrast, the lower weekly activity duration recorded by the school boy group might indicate a deficiency in the required training and effort to reach more elite playing levels.

Group means of weekly training duration and distribution of activity categories provide potentially useful information, but can mask high-effort individual outliers. Profiles of selected "highest load" case studies from each group revealed substantial differences between selected players and group means for weekly duration. In the school boy group, the case study player recorded an average weekly sport and physical activity duration of 12 ± 1 hour per week. In the representative squad, the case study player recorded a weekly duration of 13 ± 4 hours and in the talent squad, the case study recorded a weekly duration of 13.5 ± 5.5 hours. In addition to recording greater than mean weekly durations, a breakdown of weekly sport and physical activity recorded in the training diaries showed that selected case study individuals may participate in as many as three rugby games or as many as 11 rugby training sessions a week in addition to rugby related, school and other organised and recreational activities. Despite some coach influence on the type and amount of activity players participate in, the choice largely remains a decision of the individual. There is no simple explanation for factors motivating individuals to participate in higher than normal weekly durations of sport and physical activity. It is possible that more talented players may feel pressured or obligated to play for various teams within rugby union, and sometimes also across various other sports as well. Irrespective of the reasons, it is evident that some players are involved in high weekly loads, primarily participating in high demand activities such as rugby games and rugby training.

Comparative profiles of the game and training demands of other team sports are difficult to locate within the available literature on adolescent team sports. The playing habits and commitment of adolescent Australian Rules footballers have previously been described in some detail, but the need to generate a more comprehensive profile was acknowledged (Finch et al., 2002). Using self-report surveys, under 18 Australian Rules football players reported participating in up to three games and up to seven training sessions per week. These findings suggest that perhaps the pattern of training loads among rugby union players identified in this research are comparable to other adolescent team sports. More research is required to identify possible similarities in playing demands across different adolescent team sports. The training loads of individual sports are better defined in the literature (possibly because of ease of measurement), but make poor comparisons to team sports such as rugby union. Given the high impact, contact nature of rugby union (Duthie, 2006), comparisons to individual sports with differing physiological fatiguing effects would not adequately describe the relative impact of rugby union participation. Despite a lack of comparative data, the game and training demands of adolescent rugby union participation appear high. A major finding of this research is the notable differences among same group players suggesting a strong need to monitor individuals to ensure training loads and activity types are appropriately managed.

Defining optimum participation levels for adolescent rugby players remains a challenge. Maximising athlete potential is often a major goal of participation in sports and physical activities. Links exist between voluminous training hours during the younger years and athletic success among elite netball, basketball and field hockey players (Baker et al., 2003). Indeed, theories such as deliberate practice purport a direct relationship between hours engaged in deliberate practice (effortful, sport specific training) (Ericsson et al., 1993) and the level of performance achieved (Helsen et al., 1998). In the present study, evidence of deliberate practice may be seen in the high percentage of weekly activities relating to rugby. Specifically, in the talent squad, rugby and rugby related activities explained 91% of reported weekly activity duration. Despite purported benefits of such training approaches, there may be associated risks. Although differing injury definitions often complicate comparisons, injury rates are reported as being relatively high among rugby union players (Bathgate et al., 2002). Recent injury research of national representative adolescent rugby union player's found an injury incidence rate of 13.26 per 1000 training and game hours (McManus & Cross, 2004). These findings are supported by other research reporting adolescent injury rates between 7 and 18 injuries per 1000 playing hours (McIntosh, 2005). Player exposure time may be the strongest predictor of injury occurrence (Emery, 2003; Van Mechelen, Twisk, Molendijk, Blom, Snel, & Kemper, 1996), with comparatively more injuries occurring during competitive games than in training (Orchard, Marsden, Lord, & Garlick, 1997; Zemper, 2005). Players with increased weekly training and game loads or periods of intensified participation are therefore, at greater risk of injury. The possible outcomes of high volume, high intensity training is not confined to injury and could include potentially harmful consequences such as overtraining syndrome, sports burnout, increased susceptibility to illness, psychological disturbances, and performance decrements (Fry et al., 1991; Morton, 1997).

While this research contributes to the knowledge base of adolescent participation in rugby union it has not answered the question of how ideal participation is structured. Weekly loads are not well enough monitored to regulate training prescription through evidence-based guidelines or through the monitoring of individual training responses. It is clear from this research that some players are participating in many high load, high impact games and training sessions in addition to various other sports and physical activities. To better understand the individual consequence of such participation and to help establish recommendations on optimum participation it is our aim to include in future similar studies several markers of fatigue, injury and performance. Limitations of the current study include the use of subjectively determined training loads and descriptions being delimited to a single sport, precluding generalisation to other adolescent team sports. Nevertheless, the player and training descriptors provided in this study expand on existing knowledge of adolescent participation in team sport.

Practical application and conclusion

A better understanding of successful training loads is required to implement systematic planning of training prescription for adolescent athletes. A more informed approach will ideally maximise performance outcomes and minimise adverse effects such as fatigue, injury and overtraining. Errors in training, often relating to poor timing and prescription of training loads can largely be avoided by serially assaying individual’s weekly training loads. In addition, descriptors of typical training sessions for players of different skill levels might help coaches and researcher’s model skill appropriate training sessions, provide a means of training quality control, and set benchmarks for aspiring athletes. The profiling of adolescent participation in sports and physical activity may therefore, contribute significantly to talented athlete development and help nurture long-term and fulfilling participation.

Acknowledgement

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CHAPTER FIVE

STUDY TWO:

LOAD, STRESS AND RECOVERY IN ADOLESCENT RUGBY UNION PLAYERS DURING A COMPETITIVE SEASON

LOAD, STRESS AND RECOVERY IN ADOLESCENT RUGBY UNION PLAYERS DURING A COMPETITIVE SEASON

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Research Type: Original Investigation

Running Title: Stress and Recovery in Junior Rugby

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5.1 Abstract

Despite increased professionalisation of adolescent sport and improved articulation to elite adult participation, the impact of sports such as rugby union among adolescents is underexplored. This study described psychological stress-recovery responses relative to training loads in 106 male adolescent rugby union players. Results found that players with the highest training and physical activity volumes during the season demonstrated more favourable recovery-stress states compared with moderate and low volume groups. Stress and under-recovery did not increase with increases in weekly volume when assessed across a season. When assessed more acutely during intensive competition phases, stress and under-recovery increased with increases in participation demands. Despite better psychological stress and recovery profiles of more elite, higher load players, not all participants demonstrated favourable capacities to deal with stress and recovery processes. Seven of 106 participants were in at least two of three categories of highest volume, highest stress and poorest recovery. Even in the absence of fully understanding the impact of high volume, high stress, poor recovery participation among adolescent athletes these markers may be precursors for more deleterious outcomes such as injury, performance decrements, and overtraining. Findings support the efficacy of serially monitoring young athletes.

5.2 Introduction

When appropriately prescribed, participation in sport causes favourable physiological and psychological adaptations that result in improved performance (Helsen et al., 1998; Smith, 2003b). However, training loads and, or, responses to those loads may sometimes exceed individual adaptation thresholds. Subsequently, players can become overtrained with multiple associated symptoms and decreases in performance (Fry et al., 1991; Halson & Jeukendrup, 2004; Meeusen et al., 2006). In adolescent sports, undesirable training responses may present several unique challenges to normal adolescent growth and maturation, talented athlete development and optimal participation in sport and physical activity. A major role for coaches and trainers is to be cognisant of growth and maturation issues, determine the magnitude of stressors necessary to induce positive training responses and balance these with adequate recovery from such stressors to avoid maladaptations (Hooper et al., 1999; Kellmann & Günther, 2000). Determining such a balance remains a challenge and few methods exist to quantify and monitor individual responses in team sports.

The training and game demands of adolescent rugby union players have previously been described (Hartwig, Naughton, & Searl, 2008). Adolescents may frequently participate in the same or a number of sports by competing and training with several different teams representing various levels of competition. Consequently, adolescent training loads sometimes exceed those typically prescribed to elite adult athletes (Brooks, Fuller, Kemp, & Reddin, 2008). It is therefore, necessary to monitor individual adolescent training responses to reduce the risk of negative training outcomes such as overtraining. To date, limited empirical data exists amongst adolescent athletes with no known studies linking psychological responses to current training practices within available research on adolescent rugby participation.

Multiple indices for monitoring training, recovery, and overtraining exist however little agreement exists about the reliability and diagnostic potential of such measures (Urhausen & Kindermann, 2002). In addition to well published but sometimes equivocal physiological markers of training responses (Meeusen et al., 2006), psychological monitoring is purported to be an effective means of assessing individuals' responses to sport participation (Jürimäe et al., 2004). Psychological evaluation of athlete mood, particularly stress has been used extensively (Hooper et al., 1997; Martin et al., 2000; Morgan et al., 1987; Rietjens, Kuipers, Adam, Saris, van Breda, van Hamont, & Keizer, 2005). More recently the need to include psychological markers of recovery to more completely understand the short and long-term impacts of athletic participation have been argued (Kellmann & Günther, 2000; Kenttä & Hassmén, 1998). Therefore, the aim of this study was to describe psychological responses to rugby participation through assessing the stress-recovery state of adolescent rugby union players relative to training load across portions of a typical rugby season. A second aim was to determine if a dose-response relationship of psychological markers to training load existed among adolescent rugby union players.

5.3 Methods

Participants

Following approval from the University's Human Research Ethics Committee, 106 male rugby union players aged 14 to 18 years were recruited for the study. Participants were experienced rugby players (years playing 6.37 ± 3.2 yrs), who were free of injuries that would prohibit training and game participation at the time of recruitment. Parents provided written parental consent for participation. Australian Rugby Union staff assisted with participant recruitment via facilitated links with schools and teams. However, players and coaches were invited and not obligated to participate in the project. Players were subsequently recruited from six rugby teams representing three levels of adolescent rugby participation (1) school boy, (2) national representative, and (3) high performance talent squads from a selective sports school.

Research design

Psychological data and player training loads were obtained during competitive phases of rugby seasons in 2006 and 2007. Measures of psychological stress and recovery were determined using the Recovery-Stress Questionnaire for athletes (RESTQ-Sport) (Kellmann & Kallus, 2001a). Training loads via volume of participation in rugby as well as time spent in other sports and physical activity were estimated using weekly training diaries. To standardise data collection, the Recovery-Stress Questionnaire was administered prior to training sessions coinciding with two to three days after weekend rugby matches. Questionnaires were administered on two to four occasions of relatively equal time distributions during rugby seasons. Of the 332 questionnaires administered, 277 were completed (83% completion rate).

Procedures

Recovery-stress questionnaire

The Recovery-Stress Questionnaire for athletes consists of 77 items (76 plus one warm-up item) that assess the frequency of stress and recovery-related activities experienced in the past three days and nights. The questionnaire has a total of 19 scales including 12 scales of general stress and recovery and seven sport-specific scales. Seven scales assess subjective strain including; general stress, emotional stress, social stress, conflicts / pressure, fatigue, lack of energy and physical complaints. Recovery scales include; success, social recovery, physical recovery, general well-being and sleep quality. The seven sport-specific scales include stress scales; fitness / injury, burnout / emotional exhaustion, and disturbed breaks and recovery scales; fitness / being in shape, burnout / personal accomplishment, self-regulation, and self-efficacy (Kellmann et al., 2001b). Players responded to the items indicating the extent to which they related to statements in each subscale using a Likert scale from 0 (never) to 6 (always). High scores in the stress-related activities indicate high subjective stress. High scores in the recovery-related scales suggest good recovery patterns. The RESTQ has previously been validated among elite adolescent rowers aged 15-18 years (Kellmann et al., 1997) and shows good test-retest reliability for repeated measures (Kellmann, & Kallus, 2001a).

Training diaries

Training diaries were used to assist in quantitative estimates of training volume. The diaries represented a pragmatic means of longitudinally assessing training, despite acknowledged limitations (Hopkins, 1991). At the end of the last training session for the week, players completed a detailed seven day training diary. Researchers were present when diaries were completed. Players were instructed to record all sports and physical activities in the past week that had lasted 15 minutes or longer. Team coaches and coaching staff at the Australian Rugby Union confirmed that reported weekly training volumes approximated expected values. Researchers used prompts about significant days (such as game days, training days and physical education) to assist participants recall the past week's activities. To assist in the need to exclude atypical training weeks from data analyses, players completed a section on weekly injury and illness which included questions on extent to which normal training and activities had been affected.

Statistical analysis

Following tests for normal distribution, descriptive data were presented in means, standard deviations and ranges. One-way ANOVA analyses were used to compare stress and recovery differences among groups and unadjusted Bonferroni post hoc analyses were used to locate and assess the magnitude of group differences. Repeated stress and recovery measures were analysed using paired samples t-tests on two time points. Pearson bivariate correlations were performed to determine if regression analyses for factors predictive of stress and recovery could be justified. Statistical package SPSS version 14 was used and significance was accepted at an alpha level of $P < 0.05$.

5.4 Results

Descriptive data for male adolescent rugby union players representing three levels of participation are presented in Table 1. More elite, representative and talent squads were heavier than less elite school boy players and representative squad players performed greater average weekly sport and physical activity volumes compared with other teams. Scales of stress and recovery were combined to determine global overall stress and recovery. Groups were not different using 1-way ANOVA for overall stress ($p = 0.12$) or overall recovery ($p = 0.09$).

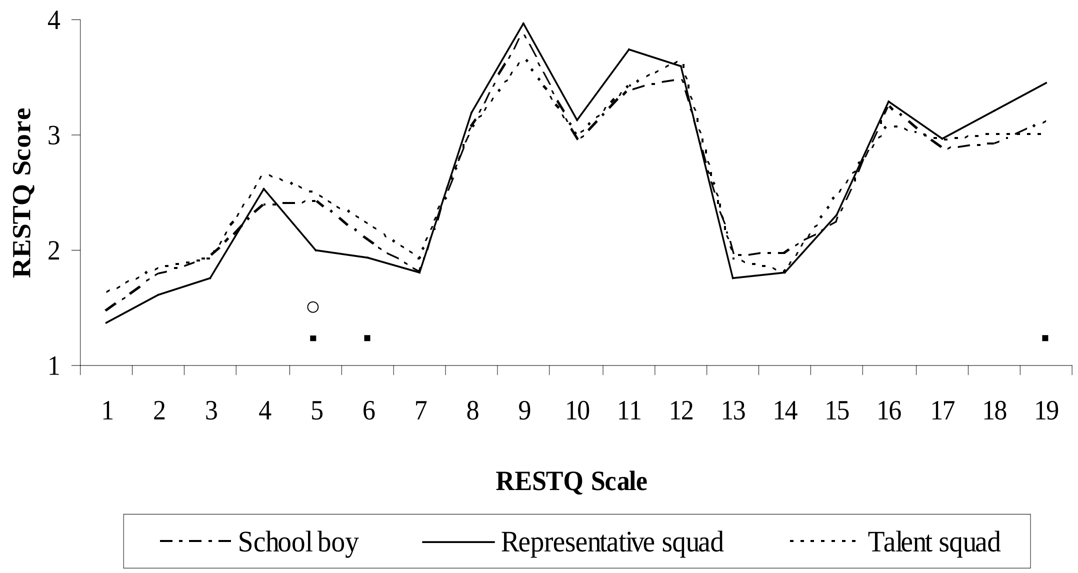
Table 5.1 Descriptive, training volume and RESTQ data (mean, ±SD or range) from three levels of male adolescent rugby union players.

	School boy (N = 29)	**Representative squad (N = 42)**	**Talent squad (N = 35)**
Age (yr)	15.2 ± 0.6	15.4 ± 0.7	16.9 ± 1.5
Height (cm)	177 ± 7	179 ± 6	177 ± 7
Weight (kg)	72.7 ± 10.2	86.5 ± 12.4**	93.6 ± 13.2**
Training volume (min/wk)	372 (216 - 514)*	607 (248 - 1026)	424 (167 - 804)*
Average global stress	2.03 (0.84 - 3.85)	1.85 (0.59 - 2.88)	2.09 (0.88 - 3.58)
Average global recovery	3.19 (1.85 - 4.83)	3.43 (2.14 - 4.78)	3.22 (1.9 - 4.58)

*Significantly different from representative squad, P < 0.001.

**Significantly different from school boy squad, P < 0.001.

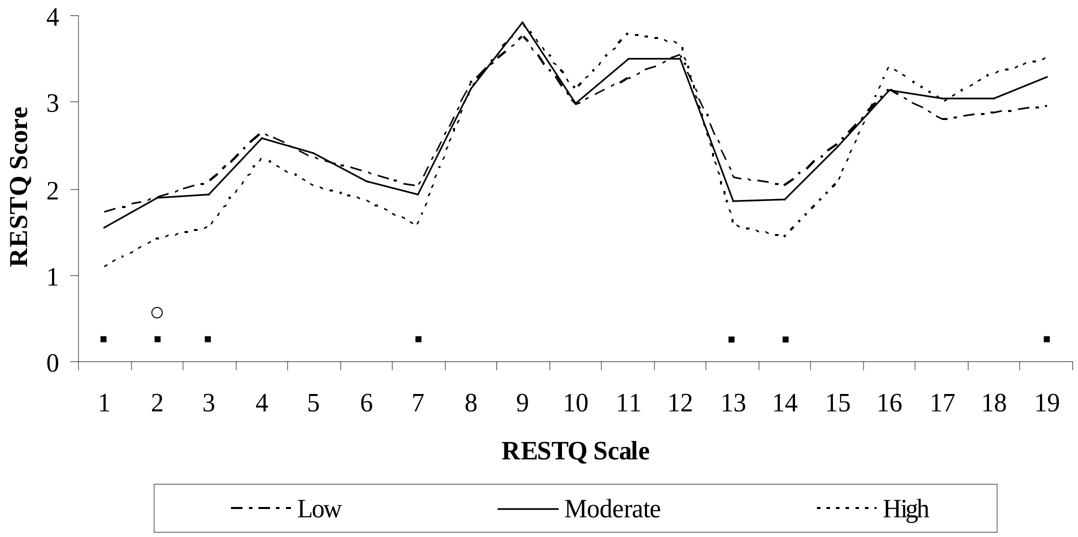
Average Recovery-Stress questionnaire scores from the 19 sub-scales for players representing three levels of adolescent participation are presented in Figure 1. Group means for the RESTQ scales were compared using 1-way ANOVA. Group differences were found for fatigue ($F_{2,267}$ = 7.14, p = 0.001), lack of energy ($F_{2,267}$ = 3.43, p = 0.034), and self-regulation ($F_{2,267}$ = 4.92, p = 0.008). Unadjusted Bonferroni post hoc analyses showed that fatigue was 21.3% higher among school boy compared with representative squads (p = 0.021) and 24.5% higher among talent than representative squads (p = 0.002). Lack of energy was 15.3% higher among talent compared with representative squads (p = 0.03) and self-regulation was 15.1% higher in representative than talent squads (p = 0.01).



1-General Stress, 2-Emotional Stress, 3-Social Stress, 4-Conflicts/Pressure, 5-Fatigue, 6-Lack of Energy, 7-Physical Complaints, 8-Success, 9-Social Recovery, 10-Physical Recovery, 11-General Well-Being, 12-Sleep Quality, 13-Disturbed Breaks, 14-Burnout/Emotional Exhaustion, 15-Fitness/Injury, 16-Fitness/Being in Shape, 17-Burnout/Personal Accomplishment, 18-Self-Efficacy, 19-Self-Regulation.

Figure 5.1 Mean scale scores for the RESTQ-Sport by team. ○Significantly different between School boy and Representative squads. ▪Significantly different between Talent and Representative squads.

To better understand the impact of serial high training volumes on measures of psychological stress and recovery, players were divided into three tertiles for average weekly training volume; low (< 357 minutes, N=32), moderate (358-542 minutes, N=40) and high (>543 minutes, N=32) volume groups. One-way ANOVA and unadjusted Bonferroni post hoc analyses found differences between high and low volume groups with the high volume group 36.1% lower for general stress ($F_{2,101} = 5.09$, $p = 0.008$) ($p = 0.008$), 24.9% lower for emotional stress ($F_{2,101} = 6.06$, $p = 0.003$) ($p = 0.012$), 25.1% lower for social stress ($F_{2,101} = 3.63$, $p = 0.03$) ($p = 0.035$), 21.6% lower for physical complaints ($F_{2,101} = 3.47$, $p = 0.035$) ($p = 0.05$), 26.5% lower for disturbed breaks ($F_{2,101} = 4.08$, $p = 0.02$) ($p = 0.016$), 28.9% lower for burnout / emotional exhaustion ($F_{2,101} = 4.22$, $p = 0.017$) ($p = 0.02$), and 18.7% higher for self-regulation ($F_{2,101} = 3.66$, $p = 0.029$) ($p = 0.026$). Differences were also found between high and moderate volume groups with the high volume group 24.9% lower for emotional stress ($F_{2,101} = 6.06$, $p = 0.003$) ($p = 0.007$). Global stress was different between groups ($F_{2,101} = 5.01$, $p = 0.008$). Post hoc analyses showed global stress was 17.7% lower in the high volume group compared with the moderate volume group ($p = 0.042$) and 21.2% lower than the low volume group ($p = 0.011$).

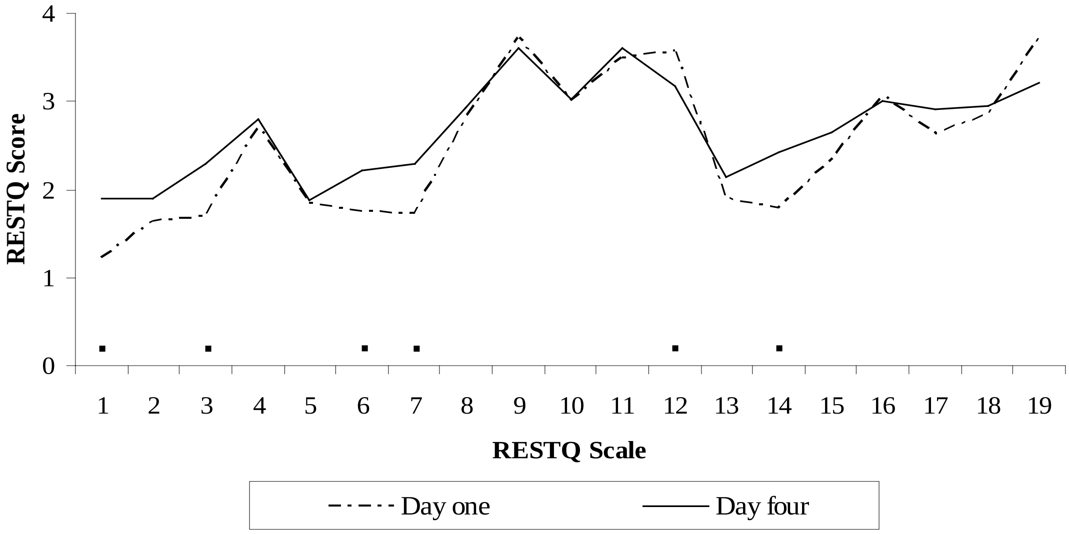


1-General Stress, 2-Emotional Stress, 3-Social Stress, 4-Conflicts/Pressure, 5-Fatigue, 6-Lack of Energy, 7-Physical Complaints, 8-Success, 9-Social Recovery, 10-Physical Recovery, 11-General Well-Being, 12-Sleep Quality, 13-Disturbed Breaks, 14-Burnout/Emotional Exhaustion, 15-Fitness/Injury, 16-Fitness/Being in Shape, 17-Burnout/Personal Accomplishment, 18-Self-Efficacy, 19-Self-Regulation.

Figure 5.2 Mean scale scores for the RESTQ-Sport by volume. ○Significantly different between Moderate and High volume groups. ▪Significantly different between High and Low volume groups.

Repeated measures of RESTQ data were analysed using paired samples t-tests. Early and late season data by whole group were compared to determine if any seasonal variations in stress or recovery existed as the competitive season progressed. Paired samples t-tests found no seasonal differences in global stress or recovery and no differences in the RESTQ sub-scales with the exception of a decrease in social relaxation (p = 0.017) between early and late season measures. Additional repeated measures analyses to determine the effect of training volume on RESTQ were difficult given the large variation in individual athletes' training load at any given time point. To determine if a relationship existed between individual athletes' training volume and their stress and recovery, a measure of the size and direction of change was calculated for volume, global stress and global recovery. Pearson bivariate correlations between change in volume, change in stress and change in recovery revealed no correlations between a change in training volume and changes in stress and recovery. Change in stress and change in recovery were negatively correlated with a weak (-0.34) but significant (p = 0.002) correlation coefficient. Weak correlations precluded the use of regression analyses.

In a sub-sample (N=18) of participants, RESTQ data were collected at two time points during a national championships competition. Data were collected on day one and day four of a five day intensive championship which comprised of daily games and, or, training. Paired samples t-tests were used to compare the stress and recovery at the beginning and end of the championships. Results are presented in figure 3. Participants reported 55.7% higher general stress (p = 0.006), 34.9% higher social stress (p = 0.04), 26.7% higher lack of energy (p = 0.018), 32% higher physical complaints (p = 0.008), 35.7% higher burnout / emotional exhaustion (p = 0.012) and 11.3% lower sleep quality (p = 0.043) on day four compared with day one of the championships. Global stress was 23.2% greater on day four than day one (p = 0.01).



1-General Stress, 2-Emotional Stress, 3-Social Stress, 4-Conflicts/Pressure, 5-Fatigue, 6-Lack of Energy, 7-Physical Complaints, 8-Success, 9-Social Recovery, 10-Physical Recovery, 11-General Well-Being, 12-Sleep Quality, 13-Disturbed Breaks, 14-Burnout/Emotional Exhaustion, 15-Fitness/Injury, 16-Fitness/Being in Shape, 17-Burnout/Personal Accomplishment, 18-Self-Efficacy, 19-Self-Regulation.

Figure 5.3 Mean scale scores for the RESTQ-Sport during a championship competition. ▪Significantly different between Day one and Day four of under 16 Championships.

Since grouped means can mask the state of individual athletes, profiles of players on a case by case basis in high percentiles for selected variables were examined for highlight at risk individuals. Data were divided into quintiles and participants in the eightieth percentile for highest weekly training volume, highest stress and greatest under recovery were examined. Of the participants in the eightieth percentile for highest volume, highest stress and poorest recovery, seven individuals were identified as being in at least two of the three categories (Figure

4). Four players were both highly stressed and poorly recovered, two players had high weekly training volumes and were poorly recovered, and one player was highly stressed and poorly recovered with a high weekly training volume.

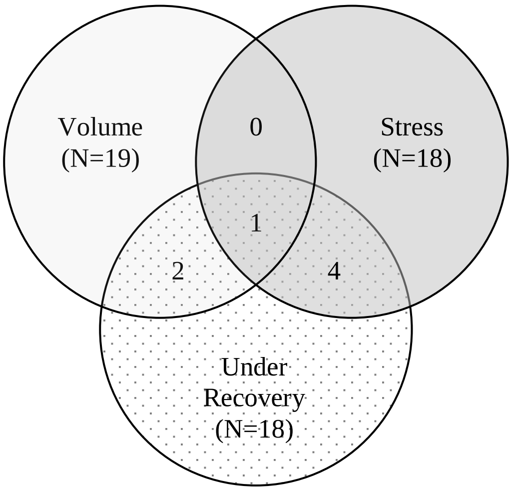


Figure 5.4 Number of participants in more than one category for eightieth percentile for weekly training volume, stress and under recovery.

5.5 Discussion

Increased professionalisation of adolescent sport and improved articulation to elite adult participation is an emerging trend in major sport. However, the impact of talent development in sports such as rugby union on adolescents is underexplored. This is the first reported study to quantify psychological stress and recovery responses relative to serial estimates of participation volumes. A major finding from the present study was that serial training volumes were often inversely related to stress and under-recovery states. Overall, players with the highest training and physical activity volumes during the season demonstrated more favourable recovery-stress states compared with moderate and low volume groups. For seven of the nineteen RESTQ sub-scales, the high volume group recorded lower stress and higher recovery, including lower global stress scores during the season compared with lower volume groups. In contrast to this finding, current research supports a dose-response relationship with acute increases in training volume and, or, intensity often associated with increased mood disturbances and decreased recovery (Armstrong & VanHeest, 2002; Coutts et al., 2007b). However, the impact of serial high loading is not well understood. Since high volume players demonstrated unexpected recovery-stress states, characteristics unique to this group of players probably best explains this finding.

High volume players most frequently participated in the more elite representative and talent squad teams. In adolescent rugby, playing for these teams represents a high level of accomplishment. High volume players were also most likely more talented, better conditioned, and more motivated than their peers. Therefore, it is not surprising that talented, successful, fit players appeared to cope better with training and external stressors and had better recovery profiles. Additionally, the positive role of sport and physical activity in psychosocial health is well established (Scully, Kremer, Meade, Graham, & Dudgeon, 1998). It is therefore, possible that high volume players experienced psychosocial benefits arising from optimal participation in sport and exercise. Results from recovery-stress scores in relation to the teams in which the athletes played, revealed lower stress and better recovery for players in the representative team for three of nineteen RESTQ sub-scales. An explanation for this observation is difficult, since many of the athletes in the high volume group played in the representative team. One likely contributing factor to this better recovery-stress profile could be that representative players were preparing for a prestigious National championship competition at the times of data collection.

The fact that high volume players and those playing in representative teams appeared to be less stressed and better recovered might also further be explained by natural selection. A selection bias might preclude players lacking resilience from progressing to more elite levels in which participation demands are greater, therefore, accounting for the higher number of talented, high volume players who appear to exhibit greater resilience and better coping strategies. Findings from the present study also suggest that factors other than training volume may account for the recovery-stress response in adolescent players. For adolescent athletes the recovery-stress state could also be sensitive to factors such as coaching styles, personality traits, injuries or illness, recovery practices and any number of internal or external stressors such as self, peer, school and parental pressure, and indeed the process of adolescence. A recent study on self-reported stressors of professional adult rugby players supports the notion that many factors contribute to a stressed state (Nicholls, Holt, Polman, & Bloomfield, 2006).

Because of the dynamic and multifaceted nature of adolescence and the need to understand individual load thresholds above which stress accumulates, the ability to serially monitor young players' responses to participation in sport would be valuable to coaches and players, and is currently lacking. In the present study, repeated measures were used to identify individual athlete's seasonal variations in psychological recovery and stress, relative to shifts in training volume and periodised phase. No differences were found between early and late season recovery-stress scores. For most players, competition demands may have been greater later rather than earlier on in the season. However, this was not always the case and training volume did not necessarily parallel increases in competition demands. Within any given team and time point, there was considerable variation in players' periodised phase since adolescents frequently participated in more than one team and, or, sport. The year-round participation observed among adolescents also made identifying specific periodisation phases problematic. The seemingly unique participation of talented adolescent athletes makes assessment of group trends difficult and justifies individual based scrutiny of volume and psychological impact.

When individual participant's serial measures of global stress, global recovery and average weekly volume were expressed as relative change, no correlations were found between change in volume and change in stress and recovery. While increases in global stress tended to correspond with decreases in global recovery, individuals' changes in stress and under-recovery did not parallel increases in weekly volume. This is not supported by previous studies of recovery-stress where a strong dose-response relationship with training volume has been reported (Jürimäe et al., 2002; Kellmann et al., 2001b; Mäestu et al., 2006). In the present study measures of changes in volume were estimated using training diary data from the week prior to and the week of RESTQ data collection. The lack of a dose-response relationship might be the result of the insensitivity of the training diary method to accurately quantify volume at the specific time of measuring stress and recovery. Despite the need for regular monitoring it may be more appropriate to use the RESTQ in more acute, high load, or high stress situations such as those reported in previous studies.

In a sub-sample of participants, repeated time measures data collected during an intensive national championship found increases in stress and under-recovery scores as competition demands accumulated. Therefore, while serial seasonal monitoring was unable to identify an association between shifts in volume and shifts in stress and recovery, more acute monitoring supported the previously identified relationship between psychological stress-recovery state and participation demands. This finding among adolescent rugby players provides a strong premise for the use of psychological monitoring of athletes in conjunction with measures of load as a potential means of strategically increasing recovery and decreasing stress at critical times during a season.

Adaptations to participation demands in sports such as rugby union vary among individual athletes. Therefore, to assist in ensuring optimal participation, there is a recognised need to avoid grouped analyses and to interpret and report individual participant's data (Martin et al., 2000). An analysis of individual athletes revealed a small number of athletes of interest. Specifically, seven participants were in at least two of three categories of highest volume, highest stress and poorest recovery. Of these seven athletes, six were from either the representative or talent squad teams. For the purposes if this study, these athletes were termed ‘at risk’ individuals. However, we acknowledge that the risk and consequence of being in more than one eightieth percentile category are not currently known. Within these limitations, it seems plausible to use such an approach to identify and potentially more closely monitor high risk individual players. Even in the absence of fully understanding the impact of ‘high volume, high stress, and poor recovery’ among adolescent athletes, these markers may be precursors for more deleterious outcomes such as injury, performance decrements, compromised longevity, and overtraining (Fry et al., 1991; Halson & Jeukendrup, 2004; Meeusen et al., 2006). While participation in adolescent rugby union, particularly at the more elite level, appears to be frequently associated with positive psychological profiles of stress and recovery, even with very high participation volumes, there are exceptions. In a recent study of burnout among young elite rugby players, a small number of at risk players emerged (Hodge et al., 2008). Similarly, relative to their peers, not all players in the present study demonstrated favourable capacities to deal with the stress and recovery processes associated with participation in adolescent rugby. In addition to the need to determine the consequences of the volume and stress-recovery profiles of adolescent rugby players reported in this study, several limitations are acknowledged. Limitations include potential underreporting with the use of training diaries to determine participation volumes among adolescent participants and the fact that results lack generalisability since participants were limited to a single sport. Although not well understood, variations in maturation may affect perceptions of stress and recovery, the absence of measures of maturation in the present study may be a limitation. Nevertheless, these results advance the understanding of team sports participation among adolescent rugby players. Further, findings support the efficacy of serially monitoring young athletes particularly at times of high competitive demands. While this current study contributes to the evidence base on adolescent participation in rugby, the consequence and impact of current practices among adolescent rugby players relative to player performance, injury, and participation longevity remain unknown.

CHAPTER SIX

STUDY THREE:

MOTION ANALYSES OF ADOLESCENT RUGBY UNION PLAYERS: A COMPARISON OF TRAINING AND GAME DEMANDS

MOTION ANALYSES OF ADOLESCENT RUGBY UNION PLAYERS: A COMPARISON OF TRAINING AND GAME DEMANDS

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Research Type: Original Investigation

Running Title: Physical Demands in Adolescent Team Sport

Key Words: Youths, team sport, athlete development, notational analysis

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6.1 Abstract

This research described the physiological demands of participation in adolescent rugby union including positional differences, and the degree to which training practices replicate game demands. Between 2003 and 2008, 118 male adolescent rugby players aged 14 to 18 years were recruited from ten teams representing three levels of adolescent rugby. Time-motion analyses using global positioning satellite (GPS) tracking devices (SPI10, GPSports Systems Pty Ltd 2003) and computer-based tracking (CBT) software (Trak Performance, Sports Tec Pty Ltd) applied to video footage determined player movement patterns 161 times during rugby training sessions and 53 times during rugby games. Compared with rugby training, rugby games were consistently characterised by more time spent jogging (14 vs. 8%), striding (3.2 vs. 1.3%), and sprinting (1.3 vs. 0.1%) ($p<0.001$). Players also covered greater distances (4000 ± 500 vs. 2710 ± 770 m) and performed more sprints (21.8 vs. 1) during games compared with training ($p<0.001$). The average sprint duration of 2 seconds was similar in games and training however, the frequency of sprint efforts in training sessions was low (1 per hour). A major finding of this study is the disparity between physical game demands and on-field rugby training practices in adolescent players determined using time-motion analyses. Sprint pattern differences between games and training in particular could have important implications for player performance during competition. Results of this study should assist in the development of game-specific training sessions and drills that provide the kinds of physically demanding experiences observed in games. Additionally, coaches could assist in

the management of adolescent players' participation loads by increasing the intensity and specificity and decreasing the volume of training.

6.2 Introduction

Among the complexities involved in the development of elite athletes, the need to employ training strategies that replicate competition performance demands is well established (Roberts, Trewartha, Higgitt, El-Abd, & Stokes, 2008; Smith, 2003b). Despite an in-principle acceptance of game-based training approaches, a major challenge is the lack of research that defines game demands and evaluates the extent to which training strategies achieve specificity. In team sports, the ability to quantify competition demands has improved as a result of advances in time-motion analysis technology (Spencer, Bishop, Dawson, & Goodman, 2005). Consequently, more accurate information about player movement demands during competition is emerging for elite athletes in popular team sports (Dawson, Hopkins, Appleby, Stewart, & Roberts, 2004b; Deutsch et al., 2007; Sirotic, Russel, Knowles, & Coutts, 2005; Spencer, Lawrence, Rechichi, Bishop, Dawson, & Goodman, 2004). Only one reported study however, has compared movement demands in training and games in a team sport to determine whether on-field training replicates games (Dawson et al., 2004). No training versus game demands research exists for adolescent athletes in team sports.

On the continuum of athlete development, adolescent athletes are encouraged to progress from the sampling years of sport participation and enter the specialisation or investment years. This next phase of sport development is characterised by a narrowed participation focus or dedication to maximising performance in a single sport (Baker & Côté, 2003). Because the pathway to intensive participation for elite athletes typically commences in adolescence, an assessment of current adolescent training practices and game demands is warranted. In addition to potentially contributing to a better level of athlete preparedness and talented athlete development, game specific training approaches may also improve training efficiencies. It has previously been reported that adolescent team sport athletes often engage in high weekly participation loads that sometimes exceed the time demands of comparable elite adult athletes (Hartwig et al., 2008). While adolescent participation in competitive sport is typically beneficial (Baxter-Jones & Helms, 1996), the impact of high loads is not fully understood and is considered to pose some risk. Further exploration is required of current training practices with the view of developing approaches that minimise risks to athlete health, performance, and long term participation, without compromising training adaptations.

Despite the potential advantages of game-specific training, in team sports it may be unrealistic and undesirable for training to consistently replicate game demands (Dawson et al., 2004). Team sports such as rugby are highly demanding, tactical and require a high level of skill (Duthie et al., 2003). Time spent on the development of these and other aspects of the game during training, limits opportunities to replicate game scenarios including appropriate work to rest ratios. Furthermore, training approaches should always function within an acceptable framework for athlete development which considers volume, intensity, duration and frequency of training according to periodised phase and athlete needs (Duthie, 2006). Nonetheless, describing and quantifying the gaps in game and training demands is a first step towards advancing the scientific training approach in the development of talented young athletes. Therefore, the aim of this study was to describe and compare the game demands and on-field training practices of adolescent rugby union players using time-motion analyses. A second aim was to compare the physical demands of different player positions.

6.3 Methods

Experimental approach to the problem

Time-motion analyses were used to determine rugby player movement patterns during on-field training sessions and games. A total of ten adolescent rugby teams participated in this research. Data were collected during teams' competition phases to describe and compare the demands of a 'typical on-field rugby training session' with a 'typical game' at the adolescent level. Each week, time-motion analysis data were collected during two on-field rugby training sessions and one game across portions of teams' rugby seasons that lasted between four and 13 weeks. Up to six players per rugby training session and three players per game were randomly selected for time-motion analyses. Player selection for time-motion analysis was rotated in an attempt to capture data representative of different positional demands and to limit bias from individual responses. Data collection involved as many players as was possible relative to time and resource constraints. Consequently, the number of individuals analysed in each training session and game varied from week to week and not all players analysed during training were analysed during games. Table 1 outlines the nature of the data collected and subsequently included in the statistical analysis.

Table 6.1 Total number of training sessions and games, number of hours, and number of times sessions were analysed between 2003 and 2008.

	Rugby Training	**Rugby Games**
Number of sessions analysed	84	20
Number of hours analysed	187.8	32.9
Number of times sessions were analysed*	161	53

*Sessions were typically full training sessions and games. Where injuries or substitutions prevented players completing games and training, a minimum of 10 minutes of data was required to be included in the analysis.

Subjects

One hundred and eighteen male adolescent rugby union players aged 14 to 18 years (mean ± SD; age 15.9 ± 0.9 years, height 1.78 ± 0.67 m, body mass 84.3 ± 11.9 kg) participated in this study between 2003 and 2008. Players and coaches were informed and agreed to the research protocols. Parents provided written consent, players less than 18 years provided assent and players 18 years and older provided consent. Players were free of injury and engaged in rugby training at the time of recruitment. Players had an average of 6 years playing experience. Players were recruited from ten rugby teams representing three levels of adolescent rugby participation (1) school boy (N=29), (2) national representative (N=54), and (3) high performance talent squads from a selective sports school (N=35). Ethical approval for this research was granted by the University's Human Research Ethics Committee.

Time-motion analyses

Time-motion analyses were performed using portable global positioning satellite (GPS) tracking devices (SPI10, GPSports Systems Pty Ltd 2003) and computer-based tracking (CBT) software (Trak Performance, Sports Tec Pty Ltd) applied to video footage to assess player movement patterns. The GPS tracking devices assessed training sessions and CBT was applied to video footage of games. Both techniques are increasingly used to monitor player movements in team sports (Edgecomb & Norton, 2006). In the present study, methodological constraints precluded the use of a single time-motion analysis technique to determine player movement patterns during games and training. Specifically, at the time of data collection the use of GPS devices during games was not permitted by rugby's governing body because of concerns for player safety. Therefore, a CBT methodology was selected to assess player movement demands during games. During rugby training sessions, GPS tracking represented a more practical means of assessing movement demands because it was possible to monitor more players, data processing was considerably less labour intensive, and access to vantage points (essential for CBT techniques) was limited at training grounds.

GPS tracking devices use earth orbiting satellites to triangulate location, yielding time, distance, and velocity data (Larsson, 2003). During training sessions, GPS tracking devices were worn between player's shoulder blades in the upper thoracic spine region. A maximum of six devices were rotated between players during data collection periods. During games, up to three digital video cameras (JVC model numberGRDVL280EA) were used to capture video footage of individual players and CBT was performed retrospectively. An elevated viewing platform was selected for filming to adequately capture players and playing fields which needed to include spatial references such as field markings to improve analysis accuracy. The CBT software allowed researchers to simulate players' locomotive patterns by observing and "tracking" video footage. Tracking occurred on a scaled version of the playing field superimposed on a drawing tablet connected to a computer. Time-motion analysis data included percent time spent stationary, walking, jogging, striding, sprinting, distance covered per hour, as well as an analysis of players sprinting characteristics.

To determine population-specific speed classifications for time-motion analyses, a subsample of players (N=25, varied field positions) walked, jogged, and sprinted through timing gates. Timing gate data were used to categorise player movements into stationary (0-1 $km.h^{-1}$), walk (1-7 $km.h^{-1}$), jog (7-12 $km.h^{-1}$), stride (12-21 $km.h^{-1}$), and sprint (21+ $km.h^{-1}$). Speed zone settings were then programmed into GPS and CBT software's. Two experienced researchers analysed game video footage. Inter and intra-rater reliability for CBT was established by two repeated analyses of the same game video footage. A 6 % coefficient of variation was achieved (Hopkins, 2000). The reliability and validity of GPS and CBT systems used to measure distance during team sports has previously been reported (Edgecomb & Norton, 2006) Comparisons between GPS and CBT showed a shared tendency to overestimate true distance by 4.8 and 5.8% respectively and had acceptable reliability with technical error of measures of 5.5 and 4.7%, respectively (Edgecomb & Norton, 2006). To our knowledge, no previous studies have investigated agreement between GPS and CBT time-motion analysis techniques with respect to player velocity. Therefore, a study was conducted to determine the efficacy of comparing GPS and CBT data. Two male participants each performed 30 laps around a 144 m circuit designed to simulate typical team sports movement patterns including time spent stationary, walking, jogging and sprinting involving many directional changes. Participants were given two minutes to perform each lap. To assess GPS and CBT velocity data over each lap, 95% limits of agreement (LoA) were calculated as ± 1.96 × standard deviation of the residual errors (Bland & Douglas, 1999; Cooper et al., 2005). LoA were calculated for time spent stationary, walking, jogging and high intensity running. Mean lap times measured using CBT and GPS, respectively were; stationary 48.9 and 47.6 s (LoA ± 5.4s), walk 38.6 and 41.8 s (LoA ± 8.9s), jog 27.2 and 25.9 s (LoA ± 8.9s), and high intensity running 5.3 and 5.2 s (LoA ± 2.2s).

Statistical analyses

Data were tested for normality. Normally distributed data are presented in means ± standard deviations (SD). Non-normally distributed data are presented in medians and interquartile ranges Data were analysed using a mixed model ANOVA to account for imbalanced numbers between groups with participants as the random effect. Mixed model ANOVA analysed dependent time-motion variables for comparisons between independent variables of game and training, and positional demands for forwards and backs. To limit inflation of type 1 errors, a Holm's correction was applied to related dependent time-motion variables by progressively adjusting the critical alpha level based on the number of comparisons made (Lundbrook, 1998). Statistical package SPSS version 17.0 was used and significance was accepted at an alpha level of $p<0.05$.

6.4 Results

Figure 1 shows differences in the median percent time spent in different movement categories during games and on-field training sessions. Percent time spent stationary (38 vs. 45%) and walking (42 vs. 45%) during games and training respectively, was not different. However, more time was spent in higher intensity movements of jogging (14 vs. 8%), striding (3.2 vs. 1.3%) and sprinting (1.3 vs. 0.1%) ($p<0.001$) during games compared with training sessions. Distance travelled during games and training, normalised for duration of play is presented in figure 2. Forwards and backs, respectively covered greater distances per one hour of play during games (3795 ± 565 and 4140 ± 460 m) compared with training (2595 ± 680 and 2920 ± 840 m) ($p<0.001$). Combined, players covered 48% more distance per hour during games (4000 ± 500 m) compared with training (2710 ± 770 m) ($p<0.001$). Table 2 presents sprint data comparisons for games and training. Compared with training, players performed more sprints per hour (22 vs. 1, $p<0.001$) and spent more time sprinting (45 vs. 2 s, $p<0.001$) during games. Consequently, the median distance sprinted during games was 313 m greater compared with training ($p<0.001$). The duration and median distance of single sprints were not different during games and training. Median maximum sprint duration was also similar in games and training.

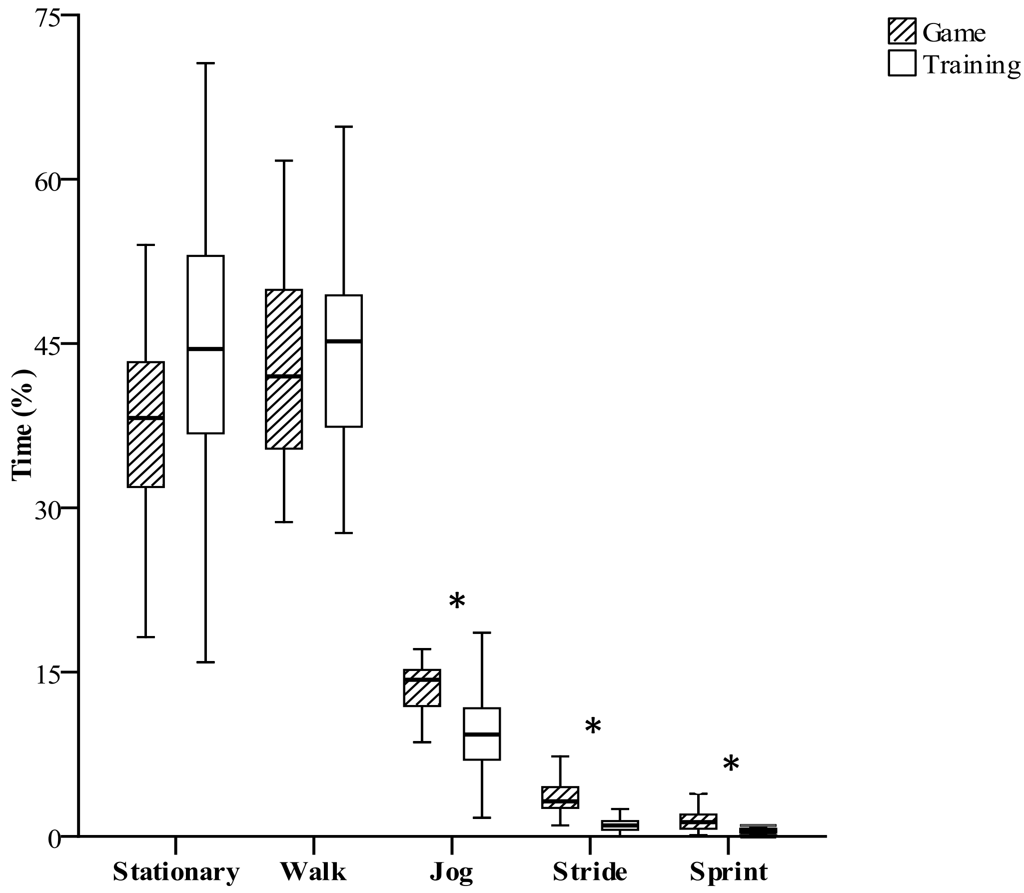

Figure 6.1 Percent of total time spent in different movement categories during adolescent rugby union games and training sessions. Data are medians and distributions of the scores. *Significantly different between game and training (p<0.001).

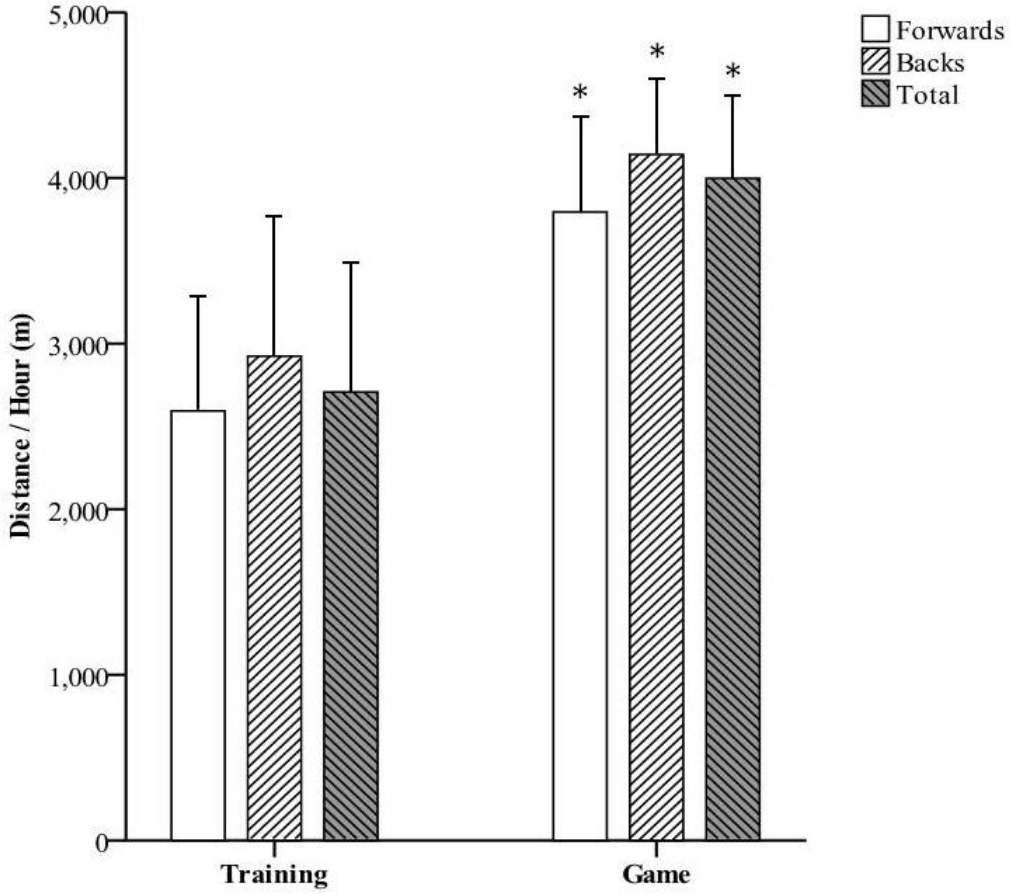

Figure 6.2 Distance per hour of play travelled by forwards, backs and forwards and backs combined during adolescent rugby games and training sessions. Data are means ± SD. *Significantly different from training ($p<0.001$).

Table 6.2 Sprint data during adolescent rugby games and rugby training sessions.

	Game (N=53)	Training (N=161)	Difference	p Value
Sprints/hour of play	21.8 (21.8) (2.9-84.6)	1.0 (3.8) (0.0-23.2)	20.8	<0.001
Sprint duration/hour of play (s)	45.0 (44.2) (2.9-160.3)	2.0 (7.6) (0.0-75.0)	43.0	<0.001
Sprint duration (s)	1.9 (0.6) (1.0-5.3)	2.0 (1.5) (1.0-5.2)	-0.1	0.350
Maximum sprint duration (s)	4.0 (3.0) (1.0-12.0)	3.0 (3.0) (1.0-14.0)	1.0	<0.001
Sprint distance/hour of play (m)	324 (319) (29-1141)	11 (43) (0-486)	313	<0.001
Sprint distance (m)	13.5 (5.0) (7.1-46.7)	11.7 (9.4) (3.0-39.3)	1.8	0.03

Medians, interquartile range, and range. N=number of sessions analysed.

Table 3 and 4 present time-motion analyses data for forwards versus backs during games and training. There were no significant positional differences during either games or training for movement category or sprint data. During games backs tended to spend less time stationary (33% vs. 45%) and more time walking (49% vs. 36%) than forwards. Backs also tended to sprint more frequently and for longer durations than forwards during both games and training, however, all positional differences were small and not significant.

Table 6.3 Percent of total time spent in different movement categories for forwards versus backs during adolescent rugby games and training sessions.

	Games		Training	
	Forwards (N=22)	**Backs (N=31)**	**Forwards (N=73)**	**Backs (N=62)**
Percent time stationary	44.5 ± 4.3	32.7 ± 7.3	44.9 ± 10.4	40.7 ± 10.3
Percent time walking	35.5 ± 4.2	48.8 ± 7.6	45.0 ± 8.8	48.1 ± 7.7
Percent time jogging	14.5 ± 2.7	13.6 ± 2.5	8.6 ± 3.1	9.1 ± 4.1
Percent time striding*	3.6 (3.5)	3.1 (1.8)	1.1 (1.1)	1.8 (1.5)
Percent time sprinting*	0.9 (2.1)	1.3 (0.8)	0.001 (0.1)	0.1 (0.4)

Data are means ± SD. *Data are medians and interquartile range. N=number of sessions analysed.

Table 6.4 Sprint data for forwards versus backs during adolescent rugby games and training sessions.

	Games		Training	
	Forwards (N=22)	**Backs (N=31)**	**Forwards (N=73)**	**Backs (N=62)**
Sprints/hour of play	17.6 (38.9)	22.0 (11.2)	0.7 (2.5)	2.1 (5.9)
Sprint duration/hour of play (s)	31.8 (69.9)	46.5 (31.2)	1.3 (5.2)	3.8 (15.3)
Sprint duration (s)	1.8 (0.6)	2.0 (0.7)	2.0 (1.4)	2.0 (1.6)
Maximum sprint duration (s)	4.0 (4.0)	5.0 (2.0)	3.0 (2.0)	4.0 (3.0)
Sprint distance/hour of play (m)	220 (552)	346 (231)	6.4 (30.8)	20.8 (96.6)
Sprint distance (m)	12.3 (5.1)	13.6 (4.8)	11.5 (8.4)	11.3 (10.6)

Data are medians and interquartile range. N=number of sessions analysed.

6.5 Discussion

In team sports, training approaches are designed to simulate the physical, tactical, psychological, and skill demands observed during competition in an attempt to prepare athletes for optimal performance. While specific training objectives alter throughout the periodised cycle, the ultimate goal of preparing athletes to compete by maximising training adaptations remains the same (Gamble, 2006). Despite considerable literature on the importance of scientific approaches for achieving optimal performance, including the need for specificity in training, this is the first reported study that evaluates the degree to which such approaches exist in adolescent team sports. A major finding of this study is the considerable disparity between game demands and on-field training practices in adolescent rugby players. Compared with typical on-field rugby training sessions, rugby games were characterised by more time spent jogging, striding and sprinting. Players also covered greater distances and performed considerably more sprints during games. Rugby training sessions analysed in this study therefore, did not adequately simulate the high-velocity, repeat-sprint demands of rugby games at the adolescent level. It should be noted that some differences in game and training movement patterns are to be expected because simply replicating game demands during training would oversimplify the multi-factorial systematic strategies involved in athlete development (Duthie, 2006). Nevertheless, findings of this present study could be used to implement important modifications to adolescent training approaches that would see a greater emphasis on training specificity.

No game and training differences were observed for lower velocity activities of time spent stationary and walking. The high proportion of time spent in these low velocity zones is similar to results of previous time-motion studies of rugby union (Deutsch et al., 2007; Duthie et al., 2005; Duthie et al., 2003). During games this is probably reflective of the nature of rugby that intermittently requires high velocity, high intensity efforts interspersed with low velocity, high intensity efforts (scrums, rucks and mauls), long recovery periods and numerous stoppages in play. During training, in addition to these factors this likely also reflects additional time spent listening to coaches and trainers, preparing for and waiting to perform drills, and other training-related activities. Game and training differences were observed for higher velocity activities, specifically sprinting patterns. These differences could have implications for athlete conditioning and performance during competition. Repeat sprint ability is a critical aspect of team sport performance (Spencer et al., 2005). Given the highly specific nature of physiological adaptations (specifically in relation to energy systems) occurring in response to high-intensity, repeat sprint training, the importance of training specificity for this aspect of rugby is paramount. While the average duration of a sprint was not different during games and on-field training (both 2 seconds), the frequency of sprint efforts in training sessions was very low (1 per training hour). It is unlikely that such sprint frequencies can elicit player adaptations necessary to optimally meet game demands. Additionally, since the ability to perform the physical and cognitive skills required during team sport games is most impacted by high intensity periods that produce fatigue (Gabbett, 2006; Roberts et al., 2008), training outcomes could benefit by having these demands simulated during on-field rugby training sessions.

Positional characteristics and differences observed during games for forwards and backs were not consistent with other time-motion analyses of rugby players (Deutsch et al., 2007; Duthie et al., 2005; Roberts et al., 2008). While our results showed similar trends to previous studies, including backs covering more distance and performing more sprints during games than forwards, no positional differences were found. Despite a lack of statistically different observations for positional demands and a need for further investigation, the observed trend during games supports the need for position specific training approaches at the adolescent level, particularly since these positional differences become evident at older levels of competition. Positional differences were also not apparent during rugby training sessions. More research is required to determine positional demands and appropriate training approaches at the adolescent level. This could also include partitioning positions more specifically than into just ‘forwards’ and ‘backs’. Importantly, for both forwards and backs differences in high intensity activities occurring during games and training sessions were still apparent.

In addition to the need to increase training specificity, results of this study also highlight the potential to improve training efficiencies. Altering current training practices at the adolescent level to improve specificity and efficiency may result in several positive outcomes. An emerging concern from a previous study of adolescent rugby union players is the high weekly training volumes accrued by some players (Hartwig et al., 2008). Mean and standard deviation weekly duration of sport and physical activity were 8.6 (±3.7) hours/week for some teams and as high as 13.4 (±5.6) hours/week for one individual player. Training volumes in this previous study of adolescents were higher than total (pre-season and in-season combined) and in-season weekly training volumes of 6.9 (± 3.5) and 6.3 (±3.1) respectively for elite adult English Rugby Premiership players (Brooks et al., 2008). While training volume comparisons should be interpreted cautiously because of methodological differences in volume estimates and participation differences between adult and adolescent players, high volumes among adolescent players are evident. The consequences of high volume participation among adolescents engaged in contact team sports are poorly understood. However, links may exist between training volume and the severity (Brooks et al., 2008) and incidence (Gabbett & Domrow, 2007; Lee & Garraway, 2001; Quarrie, Aslop, Waller, Bird, Marshall, & Chalmers, 2001) of injury in contact team sports. Moreover, reducing training volumes in semi-elite rugby league players has been shown to decrease injury rates with no negative impact on training adaptations (Gabbett, 2004). The impact of reduced training volumes on training adaptations, injury, and other potential training outcomes, such as risk of overtraining and under recovery among adolescent players, is yet to be determined. Results however, support the notion that improving training efficiency might simultaneously decrease risks associated with high volume participation while maintaining or even advancing physiological training adaptations.

The substantial volume of research in rugby union at the elite and adult level is not evident among adolescent players. Consequently, best practice approaches for young athlete development including how best to articulate with elite adult participation remain underexplored. The present study contributes to limited existing knowledge on adolescent rugby participation, but acknowledges several limitations. Matching groups for ability, training phase and training practices is a major challenge for field-based research. Future studies might therefore, benefit by performing game and training motion-analyses on more homogenous groups of players. Time-motion analyses undertaken in this study did not extend to measures of frequency of skilled movements such as tackles, kicks, and scrums. Skilled movement activities form a large part of participation in rugby and contribute significantly to total playing exertion. Analysis of skilled movement patterns would therefore, further advance the understanding of adolescent participation demands and specificity in rugby. A further limitation may lie in the use of two different time-motion analysis techniques and their imprecision which to date, continue to demonstrate some error. However, results of the method comparison study supported the use of GPS and CBT to compare training and game demands in the present study.

Practical applications

Training specificity is important for eliciting training adaptations to advance game performance. Results of this study provide useful time-motion analyses of adolescent rugby union for both games and training that should begin to facilitate changes in training approaches especially with regards to high-intensity, repeat sprint training. On-field rugby training sessions analysed in this study do not appear to simulate the high-intensity, repeat-sprint demands of rugby games at the adolescent level. Coaches might therefore, need to address this aspect of player's physical conditioning by modifying on-field training sessions. A greater understanding of the game demands at the adolescent level should assist in the development of game-specific training drills and training sessions that provide the kinds of physically demanding experiences observed in games. Additionally, coaches are also in a position to assist in the management of adolescent players' participation loads. The consequences of high participation loads observed in adolescent athletes are not known and best practice approaches for young athlete development remain underexplored. Nonetheless, coaches can contribute to load management through improving training efficiency by increasing the intensity and specificity of the training stimulus and decreasing the volume. Future research needs to explore the most appropriate mechanisms for achieving training efficiency and specificity as well as evaluating the subsequent impact on training outcomes and performance goals. It is likely that such research will contribute significantly to improvements in the approaches used by coaches and sports scientists to develop and nurture adolescent rugby players and assist in progression to elite adult participation.

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CHAPTER SEVEN

SUMMARY

7.1 Overview

The summary chapter in the thesis addresses the sequence and context of major findings. It expands on the collective implications of the studies conducted as part of this thesis. Strengths and weaknesses of the overall protocol are discussed, as well as future recommendations arising from the findings. The chapter begins with an overview of the justification for this thesis and its sequencing, including the studies conducted and their main hypotheses and contextual findings:

Limited knowledge exists to guide best practice for adolescents involved in sport. With an increasing value of the role of sports science for enhancing performance in elite sport, junior sporting pathways and adolescent athletes are of interest. The studies in this thesis involved serially monitoring participation in adolescent rugby union players. The thesis aimed to advance the understanding of factors contributing to positive performance and participation outcomes. The thesis concomitantly aimed to explore factors minimising adverse effects including serial fatigue, injury, training errors, and overtraining. The fundamental context of the research question was a better understanding of the development of talented young athletes. Within a framework of limited existing empirical evidence, studies included in this thesis were developed, in consultation with the Australian Rugby Union, to advance the understanding of the multi-faceted demands of adolescent sport and the adolescent athlete. Emphasis was placed on study methodologies with strong ecological approaches employed to ultimately better facilitate translating knowledge into practice (refer to figure 3.1, page 111).

Hypotheses

STUDY 1: Defining the volume and intensity of sport participation in adolescent rugby union players.

(i) Participation loads associated with adolescent athletes will be 'high'.

(ii) Participation loads and participation patterns will vary according to level of play.

(iii) Adolescent participation patterns will differ from adult athletes.

STUDY 2: Load, stress, and recovery in adolescent rugby union players during a competitive season.

(iv) Psychological markers of stress and recovery will be related to undesirable outcomes for some individual athletes exposed to high participation loads.

(v) A dose-response relationship will exist between psychological markers of stress and recovery, and participation loads.

STUDY 3: Motion analyses of adolescent rugby union players: a comparison of training and game demands.

(vi) Game demands will differ from on-field training practices.

(vii) Some training practices will not be optimal for the development of adolescent athletes and may contribute to risks of maladaptation.

Summary of hypotheses and findings

(i) Participation loads associated with adolescent athletes will be 'high': Results showed mean weekly loads (inferred from the product of RPE and volume data) of participation in all sport and physical activities were 'high' for adolescent rugby teams, but particularly for some individuals. The absence of comparative adolescent load data for high-impact team sports, made determining the relative impact of this participation among adolescent athletes difficult. Consequently, the loads measured in this study were considered 'high' based on limited studies quantifying load in elite adult team sports or inducing overreaching by measurably increasing training loads. Therefore, the hypothesis of high loads in adolescent athletes, relative to limited studies among adult participants was supported.

(ii) Participation loads and participation patterns will vary according to level of play: Average weekly load of sport and physical activity and time-motion analyses of rugby training varied among different levels of groups. However, the distribution of activity types within each week was similar. For all three groups, when combining rugby training, rugby games, and other rugby-related activities, results showed a majority of time per week was spent training for and competing in rugby. Consequently, a large proportion of the high weekly loads among some adolescents in this study was comprised of physical loading associated with high-impact, rugby related activities. Results also demonstrated substantive differences among 'same group' players, suggesting a strong need to monitor individuals and

ensure training loads and activity types are appropriately managed. Therefore, this hypothesis was supported, but perhaps the most salient issue not originally hypothesised was the demonstration of large intra-team variability in participation loads for adolescent players.

(iii) *Adolescent participation patterns will differ from adult athletes:* Most adolescent participants in this study reported training and competing in several different sports. Many players also reported training and competing for several different teams within any given sport. Being involved in multiple teams across a number of sports contributes to observed high weekly loads. Moreover, this multi-team, multi-sport participation by adolescents differs from the single-sport, single-team environment of the elite adult athlete. Confirmation of this hypothesis creates many additional age-specific considerations and challenges for training and developing adolescent athletes.

(iv) *Psychological markers of stress and recovery will be related to undesirable outcomes for some individual athletes exposed to high participation loads:* In contrast to the hypothesis, results of this study showed favourable stress-recovery states for adolescent athletes in the highest tertile for weekly load. Specifically, averaged results from the highest load players did not appear to show any undesirable adaptations to participation manifesting in psychological markers. However, at the individual level a small number 'highest load, highest stress, and poorest recovered' athletes were identified. This finding supported that psychological markers of stress and recovery were evident among highest load

individuals. Nevertheless, the results only partly supported the hypothesis since these markers alone, while useful for identifying at risk individuals, did not consistently indicate undesirable adaptations.

(v) A dose-response relationship will exist between psychological markers of stress and recovery and participation loads: Averaged results of this study across seasons or portions of seasons do not support the hypothesis that psychological markers of stress and recovery exhibit a dose-response relationship with participation loads. Where weekly loads increased or decreased, no corresponding changes in stress and recovery were evident. However, when stress and recovery were assessed more acutely during periods of intensified competition, a dose-response relationship was evident. Therefore, the hypothesis was partly supported.

(vi) Game demands will differ from on-field training practices: In this study, time-motion analyses revealed substantial disparity between game demands and on-field training practices in adolescent rugby players. Rugby games were characterised by more time spent jogging, striding, and sprinting compared with typical on-field rugby training sessions. Players also covered greater distances and performed considerably more sprints per unit of time during games than training. Rugby training sessions analysed in this study therefore, did not adequately simulate the high-velocity, repeat-sprint demands of rugby games at the adolescent level. Therefore, this hypothesis of differing physical demands in games and training was supported.

(vii) Some training practices will not be optimal for the development of adolescent athletes and may contribute to risks of maladaptation: High-volume, low-intensity, low-specificity training sessions observed in this study may not prepare players for the kinds of physically demanding experiences observed in games. Suboptimal training practices may inadvertently increase the relative (internal) load of games, and thus contribute to risks associated with poor preparation and high loading. Specifically, high-volume training contributed to the high weekly participation loads observed in studies one and two. A tenable theory is that load may be better managed through improving training efficiency by increasing the intensity and specificity of the training stimulus and decreasing the volume. While it remains difficult to measure the impact of training practices, the hypothesis was supported.

7.2 Discussion

In light of the major findings from this thesis, a model of participation processes and outcomes for adolescent athletes in team sports is presented in figure 7.1. For any athlete, outcomes of participating in a sport are strongly associated with processes that include the nature of training, competing, and recovering relative to individual characteristics. Whereas similar participation outcomes exist for athletes of all ages, findings from this thesis suggest additional processes unique to the adolescent athlete exist. Consequently, adolescent training and competitions demands, adolescence, and individual characteristics interact to determine specific outcomes for young athletes.

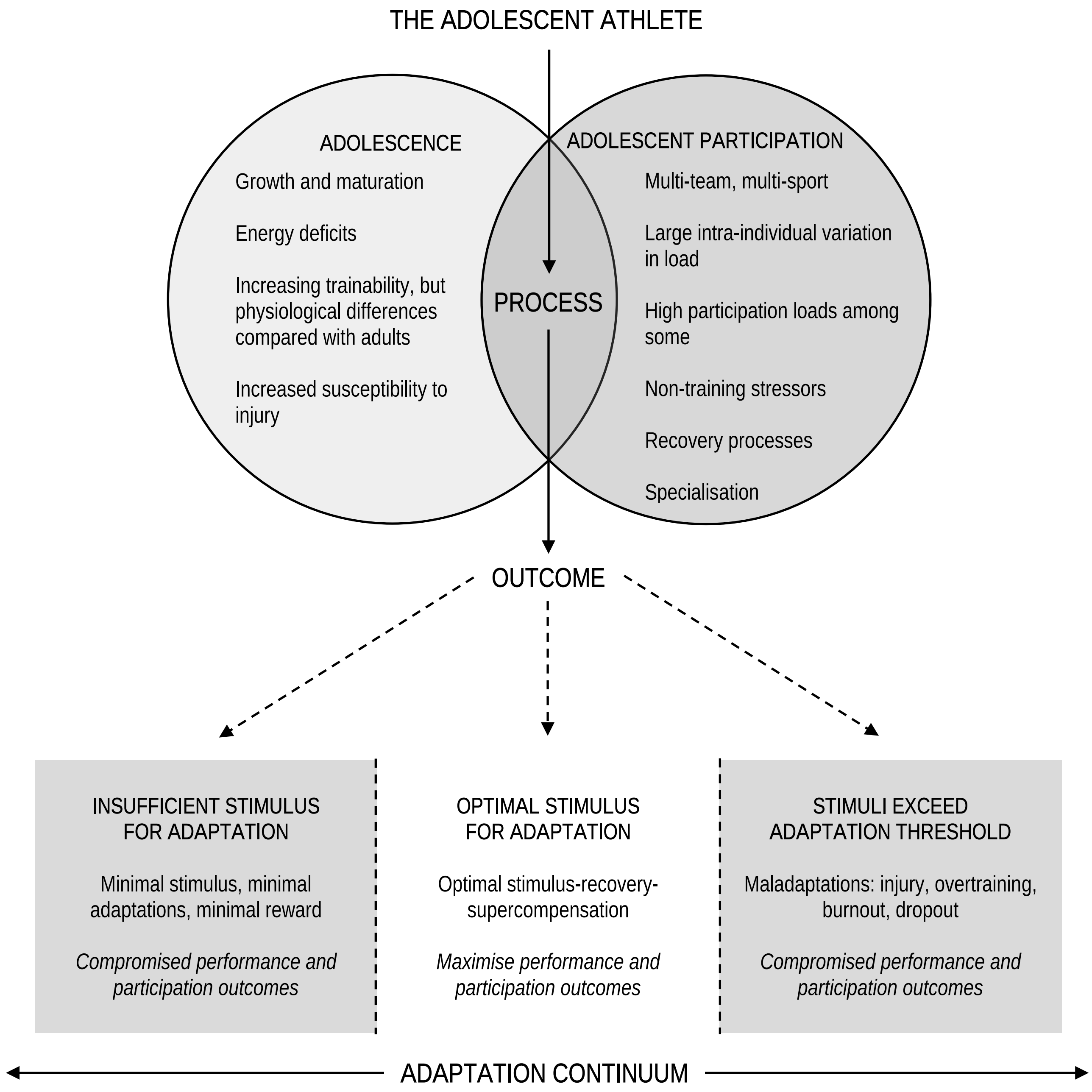

Figure 7.1 A model of the processes and expected outcomes for adolescents participating in a team sport. Implicit in the process are adolescent training and competition demands, individual characteristics, and characteristics unique to adolescents. Outcomes are influenced by the interaction of processes and are likely to be in one of three zones along a continuum of adaptations.

Adolescence and adolescent team sport participation present unique challenges for training and developing young athletes. Adolescent athletes not already engaged in deliberate practice pathways are encouraged to do so to maximise performance outcomes (Côté, 1999; Côté et al., 2007). Adolescence is therefore, a period of transition in which for some, particularly aspiring athletes, specialisation in a single sport occurs with an increasing focus on performance outcomes and goals for articulation to elite adult participation. Consequently, as young athletes reach adolescence, an increase can occur in the amount of deliberate practice undertaken. Concomitant with the transition in developmental sporting pathways, are significant physical, social, and psychological changes associated with growth and maturation.

Adolescents are well suited to training and competition demands of sport (Baxter-Jones et al., 2005). In addition to growth-related improvements in performance capacities, a marked increase in trainability coincides with puberty, particularly in males for whom hormonal changes become permissive for training adaptations. Adolescence is therefore, an optimal time to begin specialisation for articulation into elite level participation. Nevertheless, physiological differences in trainability (particularly related to anaerobic demands) between adolescents and adults remain and probably persist into early adulthood. Little is known about the impact these differences may have on the development of adolescent athletes in team sports.

It is not entirely clear why the participation loads were so high for some players monitored in the present study. However, participating in more than one sport and more than one team within the same sport may have contributed to the high loads observed and there appeared to be a culture of ‘more is better’ among some players, coaches, and parents. Managing player loads, including opportunities for recovery, is difficult in team sports. Recovering from physical stress requires time to restore the previous functional capacities of a variety of physiological and psychological systems (Kellmann, 2002). The ability to recover may be compromised in athletes with high participation loads. Participation loads observed among adolescent rugby players in this thesis comprised of both high-volume, high-intensity loading such as the relatively high number of games performed each week, as well as low-intensity, high-volume loading occurring during training. In recovering from the demands of team sports, weekly games are a recognised challenge for periodising training and recovery in elite team sport athletes (Dawson, 1996). In contact team sports such as rugby, elite athletes are therefore, rarely required, or advised, to participate in more than one game per week. The extent of the impact of multiple games per week for adolescent athletes is yet to be determined, although it is reasonable to assume risks exist. High-volume training may also impact on recovery and adaptation processes in addition to the high competition demands among adolescent athletes.

Restoring glycogen is a critical component of recovery (Jentjens & Juekendrup, 2003; Barnett, 2006). While depleted muscle glycogen has been shown to achieve adequate restoration via habitual dietary intake among adolescent football players (Zehnder, Rico-Sanz, & Kuhne, 2001), for some young athletes with high participation loads, chronic glycogen depletion is possible (Montfort-Steiger &

Williams, 2007). Additional energy drain from growth and maturation, particularly during growth spurts, as well as potentially lower glycogen storage may also impact on energy balance and is not well understood. Therefore, growth demands should be a further consideration for prescribing the loads and recovery practices of young athletes. High-load participation demands of adolescent athletes may compromise optimal energy balance and compete with physiological, psychological, and time resources available for recovery.

Associated with growth and maturation during adolescence are increased injury risks. Growing tissues, accelerated growth and development, behavioural changes, and changes in participation patterns remain potential contributors to the increased injury risk during adolescence. Exposure time is also a major contributor to injury (Emery, 2003). Young players with very high weekly participation loads, especially when (as previously described) comprised of many games, may consequently increase the risk of injury in addition to increased growth-related risks of injury. Compromised recovery and training approaches insufficiently preparing athletes for competition demands, may also contribute to the risk of young players sustaining injuries.

An assumption of participation in a team sport is that similar external loads are prescribed to all team members. This appears to be true for elite athletes for whom training appears to make extensive use of whole group exercises within carefully constructed periodised plans (Bangsbo, 1994). This characteristic of training sessions in team sport training has been used to emphasise the need to monitor individual internal training loads, since individual athletes respond differently to similar external loading (Hoff et al., 2002; Impellizzeri et al., 2005; Smith, 2003b). Among adolescent athletes studied in this thesis, participation patterns resulted in large intra-individual variability in external weekly loads. While similar loading may be applied during participation in a particular team, the accumulative loads of individuals within that team are highly varied. This challenges conventional assumptions about the nature of team sport participation. It is therefore, even more critical to monitor individual responses to participation in sport among adolescent athletes, in whom varied internal and external loads exist.

Quantifying outcomes for adolescent team sport athletes is a major challenge. Longer-term participation outcomes such as long-term athlete development, attainment of expertise, and career longevity, are difficult to determine using cross-sectional or even longitudinal approaches of moderate duration. Quantifying and exploring causal relationships between participation processes and shorter-term outcomes including performance, adaptations, recovery, and injury is also challenging. Multi-dimensional, multi-agency determinants contribute to the process of training for and competing within sport, and these appear to be even more numerous and complex among young athletes.

Despite difficulties in measuring outcomes, it is plausible that along a continuum of adaptation, performance and participation outcomes will be optimal for some adolescent team sport athletes, while among others these goals will be compromised. In team sport training approaches, it is possible for some athletes to be under-training. Insufficient stimuli from participation demands are unlikely to trigger adaptations necessary to improve performance and will consequently, compromise performance and participation outcomes. For other adolescent rugby players, training and competition demands observed in this thesis probably provide optimal stimulus and recovery, and result in a supercompensation that improves performances and nurtures long-term participation. But for others, participation loads within available time and resources for recovery probably exceed individual saturation thresholds and result in maladaptations and compromised outcomes.

7.2.1 Strengths

- In the past decade, a number of definitive reviews of literature relevant to adolescent participation in team sport pointed to deficits in the knowledge of optimal participation and athlete development for performance and participation outcomes. A strength of this thesis is the focus on some of the salient issues raised in these previous reviews, foremost of which was the need for serial monitoring of adolescent athletes.

- Few studies have used contemporary, field-based measurements to serially monitor participation in team sports to determine optimal loading, and none to date have done so among adolescents. This thesis is therefore, unique in its holistic methodology in an adolescent population. The outcomes advance limited knowledge on training and overtraining issues among young athletes in a team sport.

- Studies within this thesis were multi-disciplinary, attempting to understand physical and psychological aspects of adolescent participation in a team sport. Studies also attempted to maintain relevance to practice by selecting practical, field-based measures and consulting with team coaches and high performance coaching staff from the Australian Rugby Union.

7.2.2 Weaknesses

- Although reliability and validity for measures included in this thesis were either established or had previously been established elsewhere, field-based measures used, including subjective reporting and time-motion analyses continue to demonstrate some systematic error.

- In these field-based studies of adolescent athletes, compliance and commitment to the research requirements was individual, team, and coaching staff reliant and this posed a major challenge. Even with strong coach support, data collection was sometimes influenced by unforeseeable events such as game and training cancellations, last minute venue changes, and player absenteeism.

- The multi-team, multi-sport nature of adolescent participation can occur in concert with a combination of confounding factors interfering with comprehensive data collection. Factors include the lack of resources and expectations often associated with professional sport including athlete accountability, coaching staff priorities for research, access to medical staff, and a more structured environment to access injury incidence data. Consequently, injury data collected as part of this thesis were not included because under-reporting and compliance made it difficult to interpret.

- This thesis attempted to quantify sport-specific performance. Quantification was seen as a means of monitoring the training response, relative to high loads and selected field-based markers of maladaptation. Performance testing was difficult in this thesis. Examples of difficulties include: the absence of periodised schedules, practical limitations to field-based performance testing, sub-optimal compliance. Most significantly, an inability to control the testing environment, including the amount of loading or recovery of individual athletes leading into testing days, meant performance testing was difficult in this thesis.

- Studies in this thesis tried to be inclusive of multi-dimensional aspects capable of impacting on demands on adolescent athletes. The list of potential physical, physiological, psychosocial, behavioural, nutritional, cognitive, and environmental influences is considerably more extensive than could be included.

7.2.3 Recommendations and future directions

- Practical, simple, and effective tools such as those used in this thesis should be used to serially monitor participation loads in adolescent rugby players. Results can be useful in assisting with player management and identifying ‘at risk’ individuals. Coaching staff or volunteers within teams could be responsible for ensuring loads are monitored and information is regularly feedback to coaches and trainers responsible for player loading.

- Methods selected to monitor participation loads should be effective for players involved in more than one sport, and more than one team within sports. Monitoring methods should be able to provide information that would assist in improved coordination between different coaches of individual player’s loads and recovery.

- Despite potential limitations, more concerted efforts are required to periodise the participation loads of adolescent athletes. Evidence of periodised schedules could be used to help appropriately manage individual players, including avoiding over prescription of training and competition.

- Even in the absence of a complete understanding of the ‘risks’ associated with high participation loads, players, parents, coaches, and sporting organisations should be alerted when individual athlete’s participation loads appear ‘high’.

- Training efficiency and specificity should be improved by restructuring rugby training approaches. Restructuring could potentially reduce voluminous training loads and better prepare players for the demands of competition via increased game-specific intensity training. Training specificity for game demands should also be expanded to include position specific training. Such training approaches should be evaluated to measure the impact on performance, injury, and markers of maladaptation.

- Findings from this and other research should be used to enhance players, parents, coaches, and sporting organisations knowledge about current training and competition demands, developmental pathways, and 'risks' for adolescent players. This might help dispel 'more is better' philosophies.

- Adolescent athletes interested in talent optimisation and performance outcomes should be encouraged to specialise and reduce their multi-sport commitments. An increasing focus on specialisation appears necessary for the attainment of expertise and could assist with load management and reduce exposure related injury and overtraining risks.

- Evidence of thresholds of optimal participation loads, including the number of training sessions and matches adolescent rugby players can engage in does not exist to guide best practice or policy. An evidence-based guide is unlikely to eventuate given the extent of individual participation patterns and adaptations observed in this thesis. Nevertheless, for multi-team players with very ‘high’ participation loads, there may be merit in establishing a hierarchy of the ‘most’ important teams in which to participate as well as an index of markers of maladaptation that should be applied to athletes facing intensive demands.

- Future research should evaluate the practicality and efficacy of monitoring load in large cohorts of players. Field-based measures remain salient in potential adaption and efficacy of a monitoring system.

- Longitudinal studies should systematically evaluate the effect of current adolescent developmental pathways and training and competition demands on long-term athlete development, talent, performance, and transitions between adolescent and adult participation, as well as individual athlete health and wellbeing outcomes.

- Experimental research should elucidate the relationship between participation processes and outcomes in adolescent athletes. This may facilitate better modelling and prediction of positive and negative participation outcomes and guide adolescent developmental pathway directions.

7.3 Conclusion

Growth and maturation and adolescent sports' participation create complex challenges for training and developing young athletes. Internal and external pressures, the transition from 'sampling' to 'specialisation', and over-exaggerated short-term performance goals may independently or collectively contribute to the high participation loads found in some adolescent rugby union players. Consequently, accumulative training and non-training stressors with inadequate recovery may exceed individual adaptation thresholds with deleterious, rather than beneficial performance and participation outcomes. Quantifying such outcomes remains challenging. It is however, advantageous to identify 'at risk' individuals and appropriately manage adolescent athletes. Management should occur within redefined developmental frameworks that prioritise long-term goals, are cognisant of growth and maturation, and scientifically aim to prescribe loads and recovery in a systematic manner to avoid maladaptations.

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APPENDICES

I Ethical approval

Human Research Ethics Committee

Committee Approval Form

Principal Investigator/Supervisor: A/Prof Geraldine Naughton Sydney Campus

Co-Investigators: A/Prof Mark Anderson, Prof John Carlson, Victoria University

Student Researcher: Mr Tim Hartwig Sydney Campus

Ethics approval has been granted for the following project:
Understanding and preventing overtraining in adolescent Rugby players

for the period: 16 May 2005 to 31 October 2007

Human Research Ethics Committee (HREC) Register Number: N2004.05-40

The following standard conditions as stipulated in the *National Statement on Ethical Conduct in Research Involving Humans* (1999) apply:

(i) that Principal Investigators / Supervisors provide, on the form supplied by the Human Research Ethics Committee, annual reports on matters such as:
- security of records
- compliance with approved consent procedures and documentation
- compliance with special conditions, and

(ii) that researchers report to the HREC immediately any matter that might affect the ethical acceptability of the protocol, such as:
- proposed changes to the protocol
- unforeseen circumstances or events
- adverse effects on participants

The HREC will conduct an audit each year of all projects deemed to be of more than minimum risk. There will also be random audits of a sample of projects considered to be of minimum risk on all campuses each year.

Within one month of the conclusion of the project, researchers are required to complete a *Final Report Form* and submit it to the local Research Services Officer.

If the project continues for more than one year, researchers are required to complete an *Annual Progress Report Form* and submit it to the local Research Services Officer within one month of the anniversary date of the ethics approval.

K. Pashley.

Signed: Date: 16 May 2005
(Research Services Officer, Strathfield Campus)

II Information letter to teams

DEAR TEAM: REQUEST FOR RESEARCH SUPPORT

RESEARCH PROJECT TITLE: UNDERSTANDING TRAINING AND OVERTRAINING IN ADOLESCENT RUGBY PLAYERS

RESEARCHERS' NAMES: TIMOTHY HARTWIG and ASSOCIATE PROFESSOR GERALDINE NAUGHTON (Australian Catholic University)

Dear Coaches

Sporting organisations strive to maximise playing potential and reduce fatigue, illness, and injury risks in adolescents. Australian Rugby Union officials wish to understand more about game demands and the effects of accumulative volumes of participation on adolescent performances. The extent to which accumulative volumes of sport participation during adolescence is related to competitive success, fatigue, or injury is profoundly under explored. We aim to conduct a three phase project on physical and psychological markers of fatigue, illness and injury risk that can be influenced by training loads. We would greatly appreciate your assistance in our research.

What we would need from your school / team is:

- Access to young (14-18 years) participants of various playing levels during their training sessions and games

Specifically we are seeking volunteers who are:

- Involved in adolescent rugby training
- Would be willing to answer questionnaires and surveys relating to their nutrition, physical activity and sports involvement and subjective feelings about training as well as being willing to be tested during training and matches

Testing times will involve the following:

- Field based fitness tests which will include times for repeated maximal sprinting, agility and explosive power jumps
- Completion of training diaries and questionnaires

- ACU has recently purchased GPS tracking devices which are about the size of a mobile phone. These devices would be worn during training sessions as a means of quantifying and understanding training load

- Videotaping during games for later analysis

What we are requesting from your school / team is:

- A high level of support from coaching staff and students playing rugby and parents who are willing to have their children participate in the research

How our research may benefit the school:

- Data that we feel could be of some use to your coaches and rugby teams will be made available to the school / team as interpreted reports

- GPS and video based tracking data provide useful insight into current training techniques and as such has become an integral part of many professional sports

Approval to conduct the study has been awarded by the Ethics Committee at Australian Catholic University.

Yours sincerely

Tim Hartwig
(*Australian Catholic University)*

Associate Professor Geraldine Naughton
(*Australian Catholic University*)

John Searl
(*Australian Rugby Union*)

III Information letter to parents / guardians

INFORMATION LETTER TO PARENTS/GUARDIANS

RESEARCH PROJECT TITLE: UNDERSTANDING TRAINING AND OVERTRAINING IN ADOLESCENT RUGBY PLAYERS

RESEARCHERS' NAMES: ASSOCIATE PROFESSOR GERALDINE NAUGHTON and TIMOTHY HARTWIG (Australian Catholic University)

Sporting organisations strive to maximise playing potential and reduce fatigue, illness, and injury risks in adolescents. Australian Rugby Union officials wish to understand more about game demands and the effects of accumulative volumes of participation on adolescent performances. The extent to which accumulative volumes of sport participation during adolescence is related to competitive success, fatigue, or injury is profoundly under explored. We aim to conduct a three phase project on physical and psychological markers of fatigue, illness and injury risk that can be influenced by training volumes over seasons of rugby.

We are required to note possible risks and inconveniences to your family should you agree to your son taking part in the research. We believe the only major inconvenience will be to the participants who will be asked to fill out surveys and weekly diaries of the types and amount of physical activity they engage in. Participants will also be required to wear GPS tracking devices, which are about the size of a mobile phone. This device may provide a slight discomfort to your son during training sessions as your son would be unaccustomed to wearing it. Finger prick blood sampling for lactate may also cause some discomfort to your son. Once again standardised Australian Institute of Sport procedures will be adhered to, to minimise discomfort.

The benefit to your son will be an opportunity to take part in research that advances the understanding about factors that may increase performance and motivation and/or lead to overtraining in sport, a syndrome that eventuates in increased risk of injury and even sports' dropout. Your son will also benefit from detailed game and training session motion analysis which will provide you the parent, your son and their coach with useful statistics from the latest technology. Motion analysis statistics can be used to identify your son's individual strengths and weaknesses.

On a more universal scale this research will benefit Australian Rugby Union in their approach to the development and sound management of talented young players. Overtraining is a concerning phenomena which negatively impacts on individuals, families and the sport of rugby. It is also our intention to conduct research that will benefit other sporting organisations as well in an effort to contribute to the health and well being of all adolescents and their preferred sports.

You should note that you are free to choose not to take part in the research and to withdraw from the research at any time during the project without providing a reason. Withdrawal will not disadvantage your son's rugby training sessions or games in any way.

Data collected from your son during the project will remain within the confidence of the researchers. Reports will not identify individual players and only group results will be made available. Data will be kept securely within the office of researchers at the Australian Catholic University in Strathfield. In addition to publications in sports science journals, reports will be prepared for Australian Rugby Union.

Any questions about the above information can be obtained by contacting Associate Professor Geraldine Naughton in the School of Exercise Science at the Australian Catholic University at 40 Edward St North Sydney by telephone 9 739 2057, fax 9 739 2089, email G.Naughton@mackillop.acu.edu.au or regular mail.

In the event that you have any complaints or concerns about the way you or your son have been treated by researchers in this project or if you have any query that the researcher has not been able to satisfy, you may write to the Chair of the Human Research Ethics Committee from the Research Services Unit of the Australian Catholic University:

> Chair, HREC, Research Services
> Australian Catholic University
> Sydney Campus, Locked Bag 2002
> STRATHFIELD NSW 2135
> Telephone 02 9 701 4159, Fax 02 9 701 4350

Any complaint or concern will be treated in confidence and fully investigated. The participant will be informed of the outcome.

If you agree to you and your son participating in this project, you should sign both copies of the Consent Form, retain one copy for your records and return the other to Associate Professor Geraldine Naughton at the above address.

Yours sincerely

Associate Professor Geraldine Naughton

Tim Hartwig

IV Consent forms

ACU National

PARENT / GUARDIAN CONSENT FORM

TITLE OF PROJECT: UNDERSTANDING TRAINING AND OVERTRAINING IN ADOLESCENT RUGBY PLAYERS

NAMES OF INVESTIGATORS:

TIMOTHY HARTWIG (Australian Catholic University)
GERALDINE NAUGHTON (Australian Catholic University)
JOHN SEARL (Australian Rugby Union)
MARK ANDERSEN (Victoria University)
JOHN CARLSON (Victoria University)

I ………….. (the parent/guardian) have read (or, where appropriate, have had read to me) and understood the information provided in the Letter to Participants. Any questions I have asked have been answered to my satisfaction. I agree that my child, nominated below, may participate in this activity, realising that I can withdraw my consent at any time. I agree that research data collected for the study may be published to other researchers in a form that does not identify my child in any way.

NAME OF PARENT/GUARDIAN: ……………………………………………..
(BLOCK LETTERS)

SIGNATURE ………………………………………………….. DATE ………

NAME OF CHILD ……………………………………………………………..
(BLOCK LETTERS)

SIGNATURE OF PRINCIPAL INVESTIGATOR

……………………………………………………………………. DATE………

V Student survey

STUDENT SURVEY

(PLEASE NOTE: Answer all questions honestly, the information you provide will only be shared with your coaches in a way that does not single you out and will only be used for research purposes).

Your name: ________________________________ Birth Date: ____________

Position/s you play: ____

Town/Suburb in which you live: ________________ Home postcode: ________

The following questions are about your rugby

1. Is rugby your most serious sport? Yes/No ___________
If No, what is the sport about which you are most serious?

____

2. In general, how many rugby training sessions and matches are you involved in ***each week*** during the rugby season (include school, club and representative rugby)?

No. of training session's _________ no. of matches________

3. How many years have you been playing rugby for?

________ years

The following questions are about your recovery

1. Compared to other boys, how tiring are training and matches for you?

very tiring don't know slightly tiring not at all

2. List **4** recovery strategies that you or someone you know uses to recover from training and matches

1______________ 2 ______________ 3 ______________ 4_____________

3. What (if any) recovery strategies do you prefer to use after training and matches?

____

4. How important do you think good recovery is for your training and performances?

very unimportant unimportant not sure important very important

The following questions are about your nutrition.
(Please circle the most correct answer or complete in spaces provided)

1. How soon ***after*** a rugby training session or match do you eat some food and what do you normally eat?

How soon: ________________________ what: ____________________________

2. How soon ***after*** a rugby training session or match do you have something to drink and what do you normally drink?

How soon: ________________________ what: ____________________________

3. Do you drink anything ***during*** rugby training and matches?

never sometimes most times always

4. Do you take any vitamin and mineral supplements, if so what type and how often?

Type: _____________________________ how often: ______________________

5. Do you take any protein, creatine or other sporting supplements, if so what type and how often?

Type: _____________________________ How often: _______________________

THANK YOU FOR YOUR PARTICIPATION!

VI Training diary

MY WEEKLY TRAINING DIARY

Training diaries are used by athletes as a way of working out the amount of training they are doing. It is very important that training diaries are filled in accurately. Training diaries will be completed at training each week. Thank you for your help.

1	No effort at all
2	Very light
3	Light
4	
5	Somewhat hard
6	
7	Hard (heavy)
8	
8.5	Very hard
9	
9.5	Extremely hard
10	Maximal effort

How hard were my activities?

Use this table when trying to decide how hard your activities were and write the number.

For example, if you had an easy rugby training session that wasn't very challenging, didn't make you feel very tired or you didn't work as hard as you normally do you might give that activity a number **5** or **6**.

Or maybe you played your heart out in a game on the weekend and it made you feel very tired and sore. You might give that activity a number **9** or **10**.

This diary has 3 parts:

This is an example of how to fill in your training diary

1) Activities

- Backyard/schoolyard games
- All organized sports and activities
- Jogs, walking to shops etc
- Social activities like touch with friends

2) How long

Include all physical activities that you did for ***more than 15 minutes***

3) How hard

Write down the number from the table above

Example	Monday	Tuesday	Wed.
Activity 1	Rugby training	Weight training	Game of touch
How long	45 minutes	25 minutes	20 minutes
How hard	6	9	4
Activity 2	PE lesson	One on one basketball	Walk to the shops
How long	30 minutes	25 minutes	15 minutes
How hard	5	6	3

	Today	Yesterday	Tuesday	Monday	Sunday	Saturday	Friday
Activity 1 **How long** **How hard**							
Activity 2 **How long** **How hard**							
Activity 3 **How long** **How hard**							
Activity 4 **How long** **How hard**							
Activity 5 **How long** **How hard**							
Activity 6 **How long** **How hard**							

HOW I FELT ABOUT MY TRAINING THIS WEEK

The following questions are about how you felt about training and matches this past week. There are no right or wrong answers, just ***circle*** the answers that best describe your feelings.

1. **How much effort was needed to complete my training and matches last week?**

0	1	2	3	4	5	6
hardly any effort						excessive effort

2. **How recovered did I feel before my workouts and matches this last week?**

0	1	2	3	4	5	6
still not recovered						feel energized and recharged

3. **How successful was I at rest and recovery activities this last week?**

0	1	2	3	4	5	6
not successful						very successful

4. **How well did I recover physically this last week?**

0	1	2	3	4	5	6
never						always

5. **How satisfied and relaxed was I as I fell asleep in the last week?**

0	1	2	3	4	5	6
never						always

6. **How much fun did I have this last week at training and matches?**

0	1	2	3	4	5	6
never						always

7. **How sure was I that I could achieve my goals during performances last week?**

0	1	2	3	4	5	6
never						always

HOW WAS MY HEALTH THIS WEEK

1. Were you injured this week and if so what was the injury?

Yes/No____________ what injury____

2. Were you sick this week and if so what was wrong?

Yes/No____________ what illness____

3. If you answered yes to question 1 or 2, do you think that your injury or illness negatively affected your training and matches this week?

Yes/No____________

4. Did an injury or illness cause you to miss any training or matches this week, if so how many?

Yes/No____________ how many ____

5. Did you take any medication this week and if so what medicine did you take?

Yes/No____________ what medicine ____

6. This week, how much stress did you feel from any of the following: school, family, work and/or friends?

0	1	2	3	4	5	6
hardly any stress			some stress			lots of stress

THANK YOU FOR YOUR PARTICIPATION!

VII Publications / presentations

Publications

1. Hartwig, T. B., Naughton, G., & Searl, J. (2009). Motion analyses of adolescent rugby union players: a comparison of training and game demands. *Journal of Strength and Conditioning Research*, under review.

2. Hartwig, T. B., Naughton, G., & Searl, J. (2009). Load, stress and recovery in adolescent rugby union players during a competitive season. *Journal of Sports Sciences, 27*(10), 1087 – 1094.

3. Hartwig, T. B., Naughton, G., Searl, J. (2008). Defining the volume and intensity of sport participation in adolescent rugby union players. *International Journal of Sports Physiology and Performance, 3*, 94-106.

4. Hartwig, T. B., Naughton, G., & Carlson, J. (2008). Understanding participation among adolescent rugby union players. Children and Exercise XXIV Pediatric Work Physiology Meeting. University of Tartu, Estonia. In; Jurimae, T. (Ed). In press.

Presentations

1. **2008**- Psychological stress and recovery in adolescent rugby union players during competitive seasons. Australian Conference of Science and Medicine in Sport, Hamilton Island (podium presentation).

2. **2008**- Understanding volume, intensity and specificity of participation in adolescent rugby union. Football Australasia Conference, Melbourne (poster presentation).

3. **2007**- Tracking the volume and intensity of sport participation in adolescent rugby union players. Australian Conference of Science and Medicine in Sport, Adelaide (podium presentation).

4. **2007**- Understanding participation among adolescent rugby union players. Pediatric Exercise Science Conference, Estonia (poster presentation).

5. **2006**- Motion analyses of adolescent rugby union players: linking training and game demands among under 16 players. Australian Conference of Science and Medicine in Sport, Fiji (podium presentation).

VIII Poster presentations

Understanding Volume, Intensity, and Specificity of Participation in Adolescent Rugby Union

Timothy Hartwig[1], Geraldine Naughton[1], John Searl[2]
[1]Australian Catholic University, School of Exercise Science, Centre of Physical Activity Across the Lifespan, Sydney, Australia,
[2]Australian Rugby Union, Sydney, Australia

Introduction

- Training and game demands in adolescent sports remain largely unknown
- Consequences of excessive participation are a major concern for adolescent sports
- Quantifying and monitoring adolescent participation in sports such as rugby union may help determine optimum participation load prescription
- Advances in notational analysis technology allow accurate assessment of current participation practices and could contribute towards improved training efficiency and game specificity

Aims

- To use notational analyses and self-reporting to define current participation loads and compare training and competitive games demands among adolescent male rugby union players

Methods

Seventy-five male rugby union players aged 14 to 18 years from three levels of rugby participation

School-Boy → Representative → Talent Squad

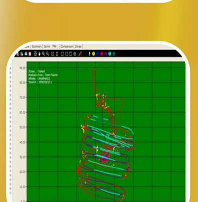
	School (N = 29)	Reps (N = 27)	Talent (N = 18)
Age (yr)	15.2 (± 0.6)	15.6 (± 0.7)	16.4 (± 1.5)
Height (cm)	177 (± 7)	180 (± 6)	179 (± 7)
Weight (kg)	72.7 (± 10.2)	87.3 (± 12.9)*	93.3 (± 13.1)*
Years playing rugby	5.2 (± 3.0)**	7.4 (± 3.1)	5.1 (± 2.5)

Table 1- Descriptive data (mean ± SD) from three levels of male adolescent rugby union players.
*Significantly different from school boy, P < 0.001.
**Significantly different from representative squad, P = 0.027

Training

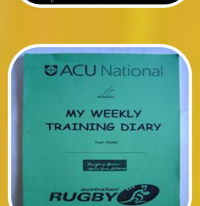
Geostational Positioning Satellite tracking devices used to determine training demands

Games



Computer based tracking technology (Trakperformance) used to determine game demands

Load



Training diaries used to quantify total weekly sport and physical activity demands

Weekly Participation Loads	Physical Demands of Competition
Outcome Variables	
Group and Individual Variations	Physical Demands of Training

Statistical Treatment

- Independent t-tests compared game and training differences
- One-way ANOVA compared differences among the three groups (unadjusted Bonferroni post hoc analyses)
- Significance accepted at of P < 0.05, using SPSS V.14

Results

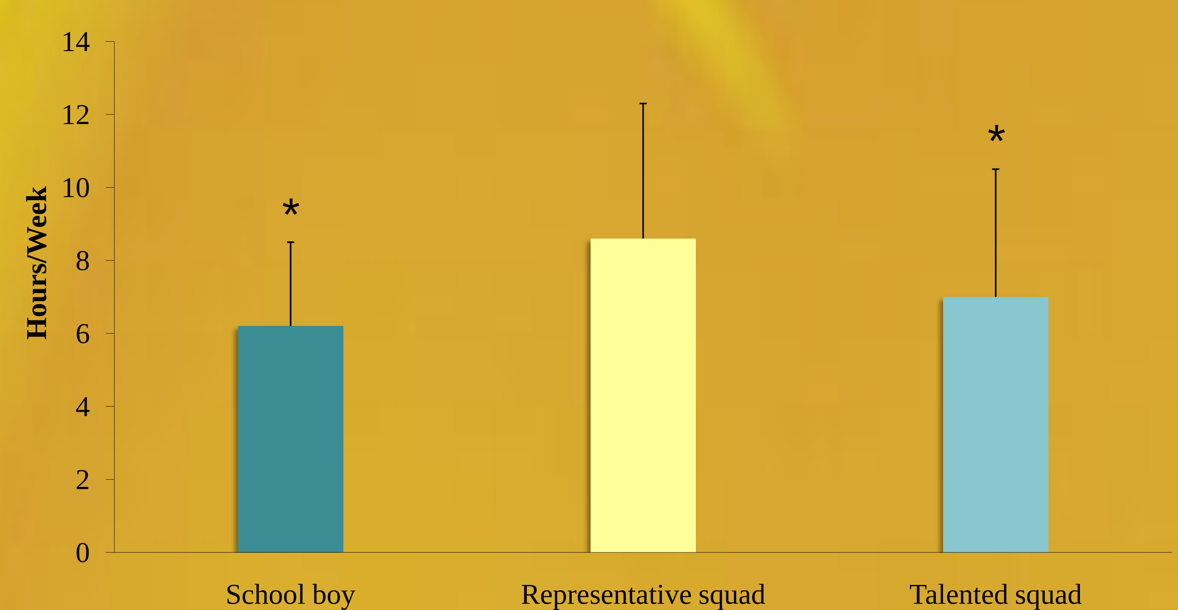


Figure 1 - Mean weekly sport and physical activity duration for three levels of participation. *Significantly different from Representative squad, P < 0.001.

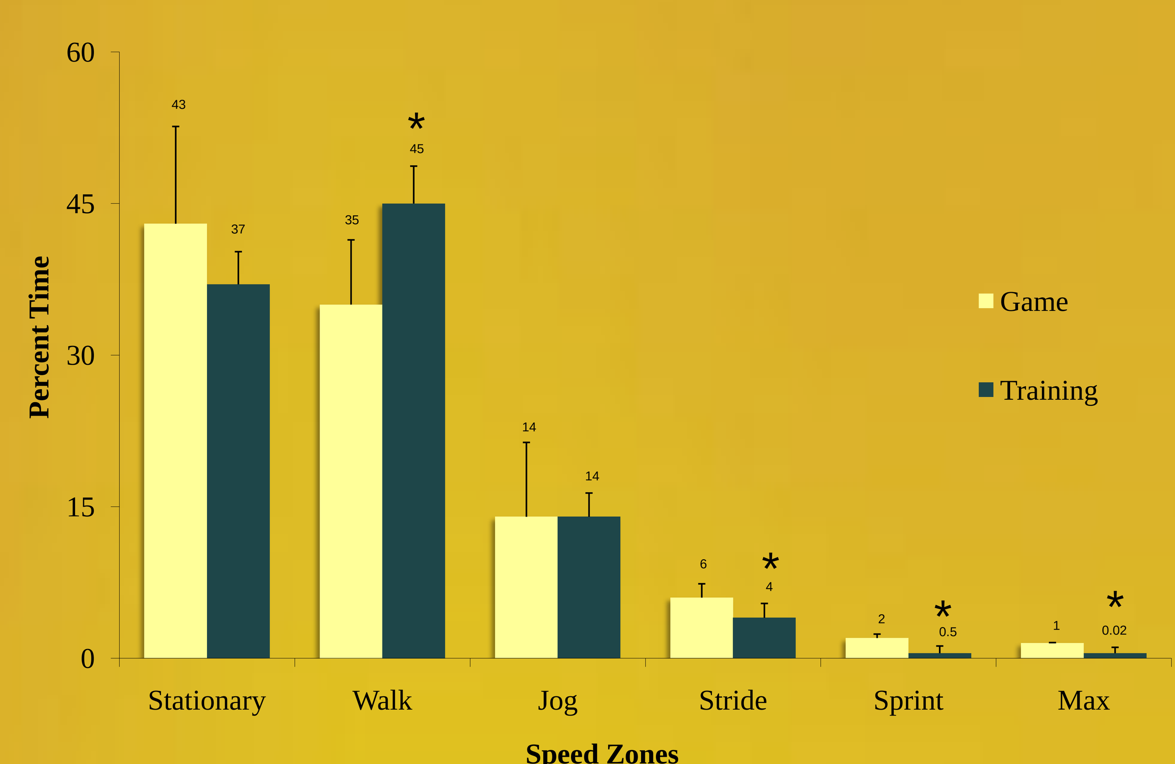


Figure 2 – Movement analysis comparison of games versus training sessions, percent time spent in movement categories. *Significantly different from game, P < 0.05.

	Game	Training
Average Distance (km)	5.8	4.4*
Average Distance/Hour	4.3	3.3*
Time Spent Sprinting (s)	108	33*
Percent Time in Low Intensity Movements	91	95
Percent Time in High Intensity Movements	9	5*

Table 2- Adolescent rugby games versus training.
*Significantly different from game, P < 0.05.

Major Findings

1. Weekly duration of all sports and physical activities appear high among adolescent athletes
2. Results showed large individual variations in weekly loads with "high-effort players" participating in up to 19 hours of sport and physical activity including as many as 3 games or 11 training sessions per week
3. Results of notational analyses indicate relative homogeneity between games and training for percent time spent at lower intensities of stationary, walk and jog
4. Games and training differ considerably at higher movement intensities of stride, sprint and maximal sprinting as well as distance covered

Conclusions

- Despite links between voluminous, intensive adolescent training approaches and athletic success, associated individual risks may include injury, overtraining syndrome, burnout, and performance decrements
- Large training load differences within teams suggests a strong need to monitor individuals and ensure training loads and activity types are appropriately managed
- Game and training notational comparisons identified differences in usual moderate to vigorous physical demands of training compared with games
- Results suggest a potential for adolescent training approaches to more closely reflect game demands
- 'Game-based' training might improve training efficiency and subsequently reduce high volume training loads that may contribute to deleterious participation outcomes
- A more scientific approach to adolescent rugby training and participation practices could maximise player performance and career longevity and minimise maladaptations.

Acknowledgments

We wish to acknowledge the support of the Australian Rugby Union and the New South Wales Sporting Injuries Committee

Understanding Participation Among Adolescent Rugby Union Players

Timothy B. Hartwig[1], Geraldine Naughton[1], John Carlson[2]

[1]Australian Catholic University, School of Exercise Science, Centre of Physical Activity Across the Lifespan, Sydney, Australia,
[2]Victoria University, Melbourne, Australia

Rugby: show your true colours

Background

- Training and game demands in adolescent sports are becoming increasingly adult-like but remain largely unmonitored
- There is a paucity of evidence based studies among adolescent rugby players quantifying typical training and game loads
- Therefore a need exists to quantify and monitor adolescent participation in sports such as rugby union to determine optimal work loads
- Advances in notational analysis technology such as GPS tracking systems permit objective assessments of training demands

Purpose

- To use notational analyses and self-reporting to define the current level of physical demands during a typical rugby season including training, competitive games and all other sport and physical activities in adolescent male rugby union players
- An additional purpose was to define the variation in activity patterns for varying levels of participation.

Methods

PARTICIPANTS

- 75 male rugby union players aged 14 to 18 years from three levels of rugby participation:

1. School Boy
2. National Representative
3. Selective Talent Squad

MEASUREMENTS

Volume and intensity of participation in rugby was estimated using Global positioning satellite (GPS) technology

Volume and intensity of participation in other sports and physical activities was estimated using training diaries

Table 1- Descriptive data (mean ± SD) from three levels of male adolescent rugby union players

	School boy (N = 29)	Representative squad (N = 27)	Talent squad (N = 18)
Age (yr)	15.2 (± 0.6)	15.6 (± 0.7)	16.4 (± 1.5)
Height (cm)	177 (± 7)	180 (± 6)	179 (± 7)
Weight (kg)	72.7 (± 10.2)	87.3 (± 12.9)*	93.3 (± 13.1)*
Years playing rugby	5.2 (± 3.0)**	7.4 (± 3.1)	5.1 (± 2.5)

*Significantly different from school boy, P < 0.001.
**Significantly different from representative squad, P = 0.027

Table 2- Rugby training and GPS analyses descriptive data

	School boy (N=35)	Representative squad (N=19)	Talented squad (N=20)
Hours analysed (h/m)	104:54	37:45	43:48
Test frequency	90	25	46
Mean session duration (h/m)	1:12 (± 0:18)	1:33 (± 0:19)	0:58 (± 0:12)
Distance per hour of training (km/h)	3.0 (± 0.76)	2.4* (± 0.85)	2.3* (± 0.42)

*Significantly different from school boy, P < 0.001.

OUTCOME VARIABLES

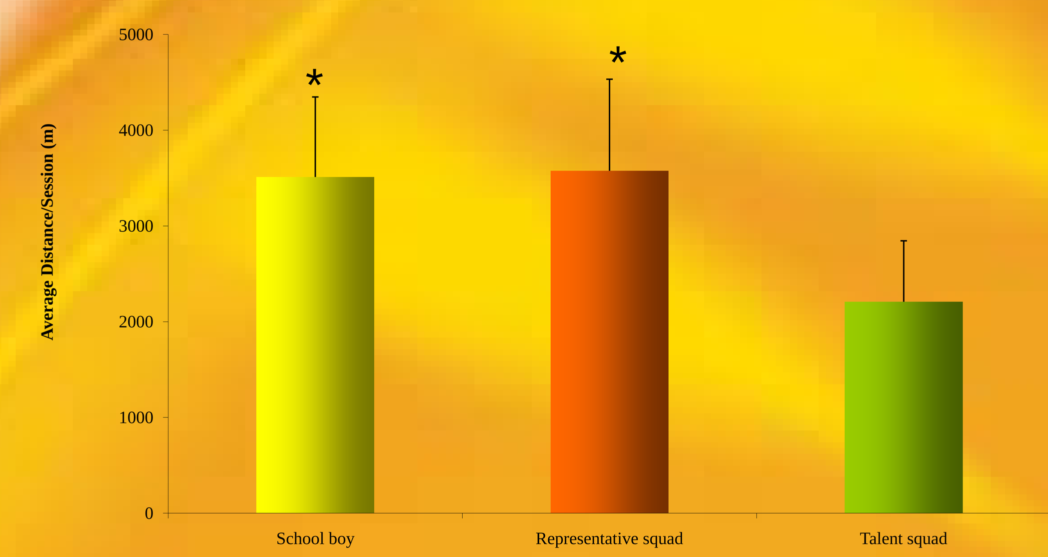
- Average Distance per Rugby Training Session
- Duration of all Weekly Sports and Physical Activities
- Distribution of Weekly Sports and Physical Activities

Statistical Treatment

- Descriptive statistics presented, all data tested for normal distribution
- One-way ANOVA was used to compare differences among the three groups
- unadjusted Bonferroni post hoc analyses were used to locate and assess the magnitude of differences.
- Significance was accepted at an alpha level of P < 0.05, SPSS V.14 used for analyses.

Results

RUGBY TRAINING



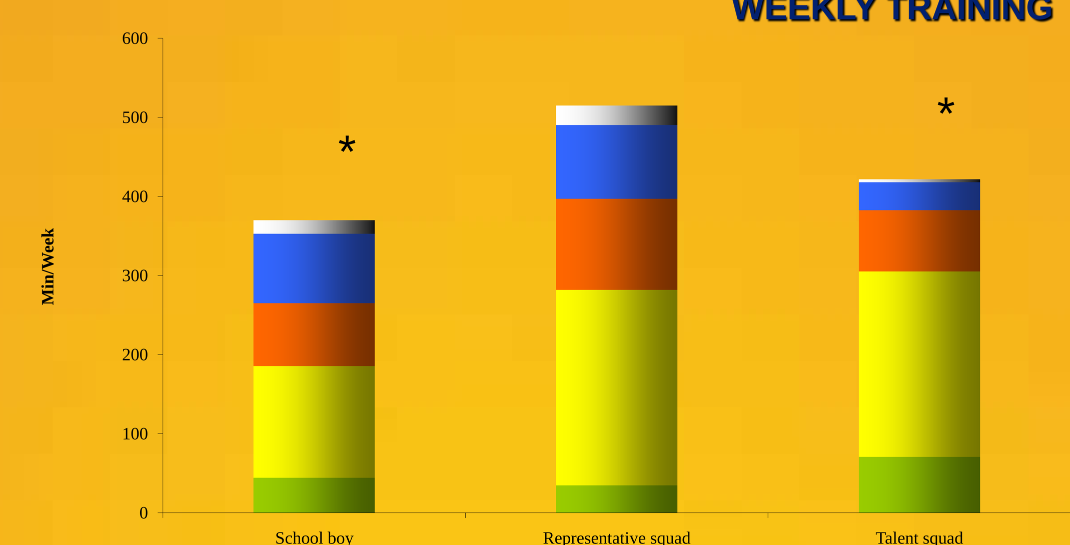
Distance/Session (m)

School Boy	3511 (± 836)
Rep Squad	3576 (± 956)
Talent Squad	2208 (± 637)

ANOVA [F (2, 158) = 43.96, P = < 0.001]

Figure 1 - Mean distance in meters per session for three levels of participation assayed using repeated GPS analyses across the rugby season. *Significantly different from Talent squad, P < 0.001.

WEEKLY TRAINING



Weekly Duration (min)

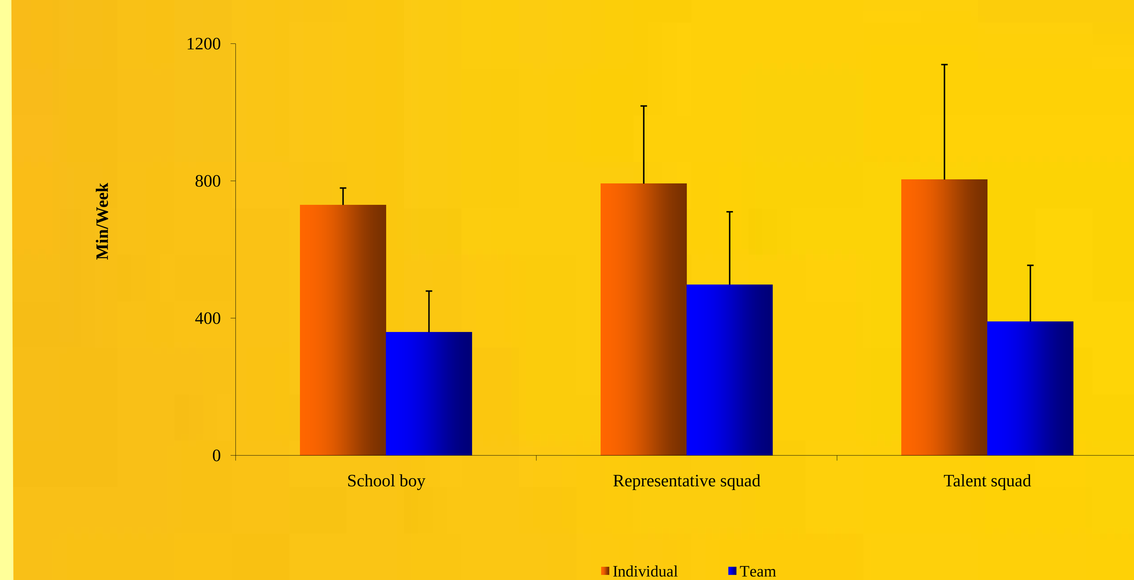
School Boy	370 (± 135)
Rep Squad	515 (± 222)
Talent Squad	421 (± 211)

ANOVA [F (2, 392) = 21.02, P = < 0.001]

Figure 2 – Mean total weekly duration and a breakdown of weekly activities in minutes/week reported in training diaries. *Significantly different from representative squad, P < 0.001.

[a] Rugby game, [b] rugby training, [c] rugby related, [d] school/other organised, [e] recreational

INDIVIDUAL CASE STUDIES



Case study Durations (min/week)

School Boy	730 (± 49)
Rep Squad	792 (± 226)
Talent Squad	804 (± 335)

Figure 3 – Individual vs. rest of team average weekly duration of sport and physical activity in minutes per week

Major Findings

1. Differences existed among groups in measures of typical rugby training session loads such as distance travelled
2. Mean distance covered during sessions did not necessarily increase with talent rating of players with the most talented group recording the lowest average training distance per session
3. Despite a lack of comparative data, weekly duration of all sports and physical activity appear high with large differences among same group players
4. Individual high-effort players may be participating in up to 19 hours of sport and physical activity including as many as 3 games or 11 training sessions per week

Conclusions

- Defining optimum participation levels for adolescent rugby players remains a challenge.
- Maximising athlete potential is often a major goal of participation in sports and physical activities and links exist between voluminous training hours during the younger years and athletic success
- Despite purported benefits of intensive adolescent training approaches, there may be associated risks including injury, overtraining syndrome, sports burnout, increased susceptibility to illness, psychological disturbances, and performance decrements
- Differences within the same group of players suggest a strong need to monitor individuals to ensure training loads and activity types are appropriately managed.
- The question of how ideal participation should be structured is yet to be answered.
- A better understanding of successful training loads is required to implement systematic planning of training prescription for adolescent athletes.
- It is hoped a more informed approach will maximise performance outcomes and minimise adverse effects such as fatigue, injury and overtraining.

Acknowledgments

We wish to acknowledge the support of the Australian Rugby Union and the New South Wales Sporting Injuries Committee

IX PhD defense presentation

PhD Defense Presentation

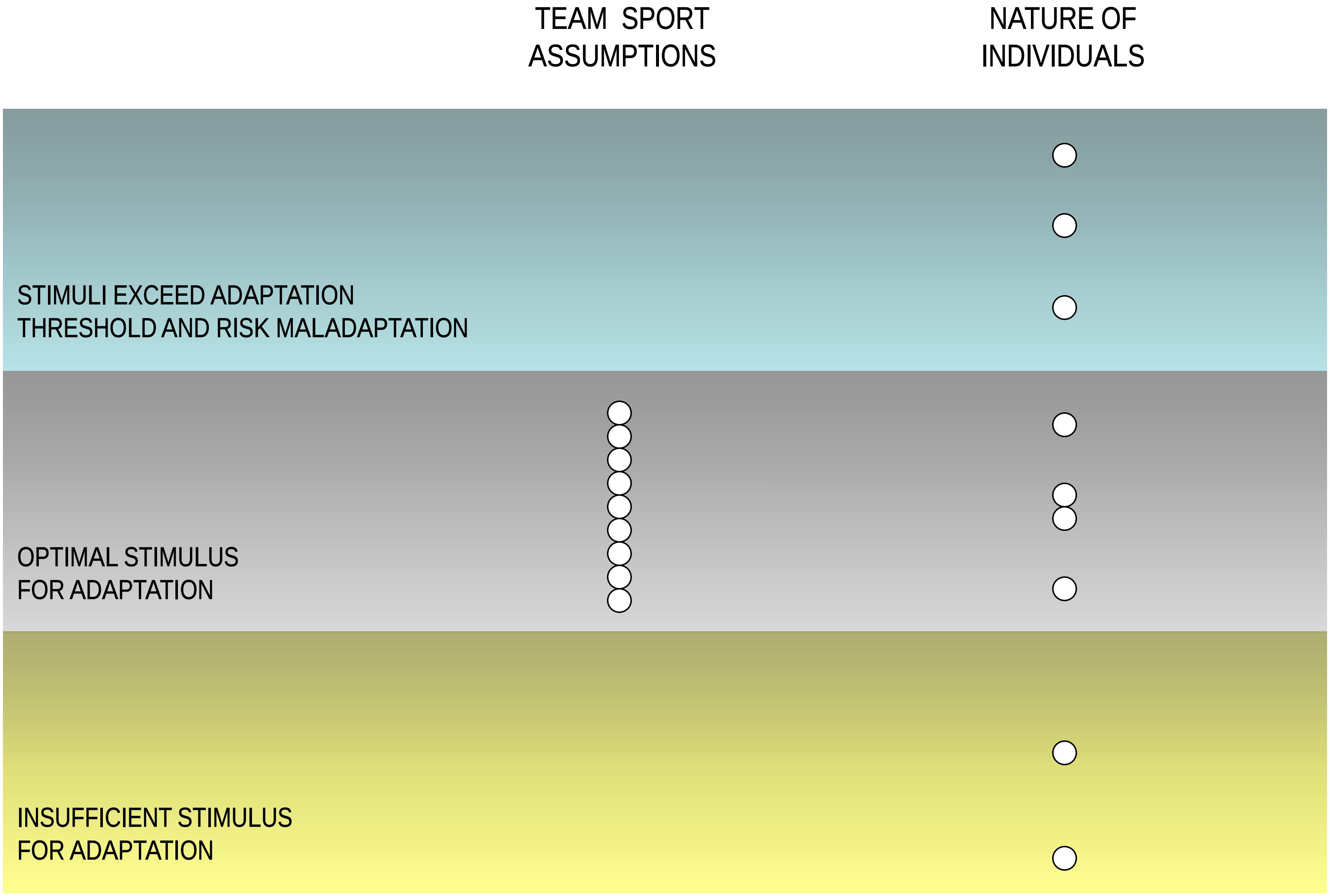
Training and Competition Demands of Adolescent Rugby Union Players

Timothy Hartwig

Australian Catholic University, School of Exercise Science,
Centre of Physical Activity Across the Lifespan, Sydney, Australia

Adolescent Sport

- **Participation in sport + develop talent and maximise athletic success**
- **When appropriately prescribed sports participation associated with positive adaptations**
- **Articulation to elite 'adult' - adolescence**
- **Adolescents appear to be increasingly engaged in strenuous training processes**
- **Strenuous training necessary to achieve performance goals - what's optimal?**


TEAM SPORT ASSUMPTIONS
NATURE OF INDIVIDUALS
STIMULI EXCEED ADAPTATION THRESHOLD AND RISK MALADAPTATION
OPTIMAL STIMULUS FOR ADAPTATION
INSUFFICIENT STIMULUS FOR ADAPTATION

Adolescent Athletes

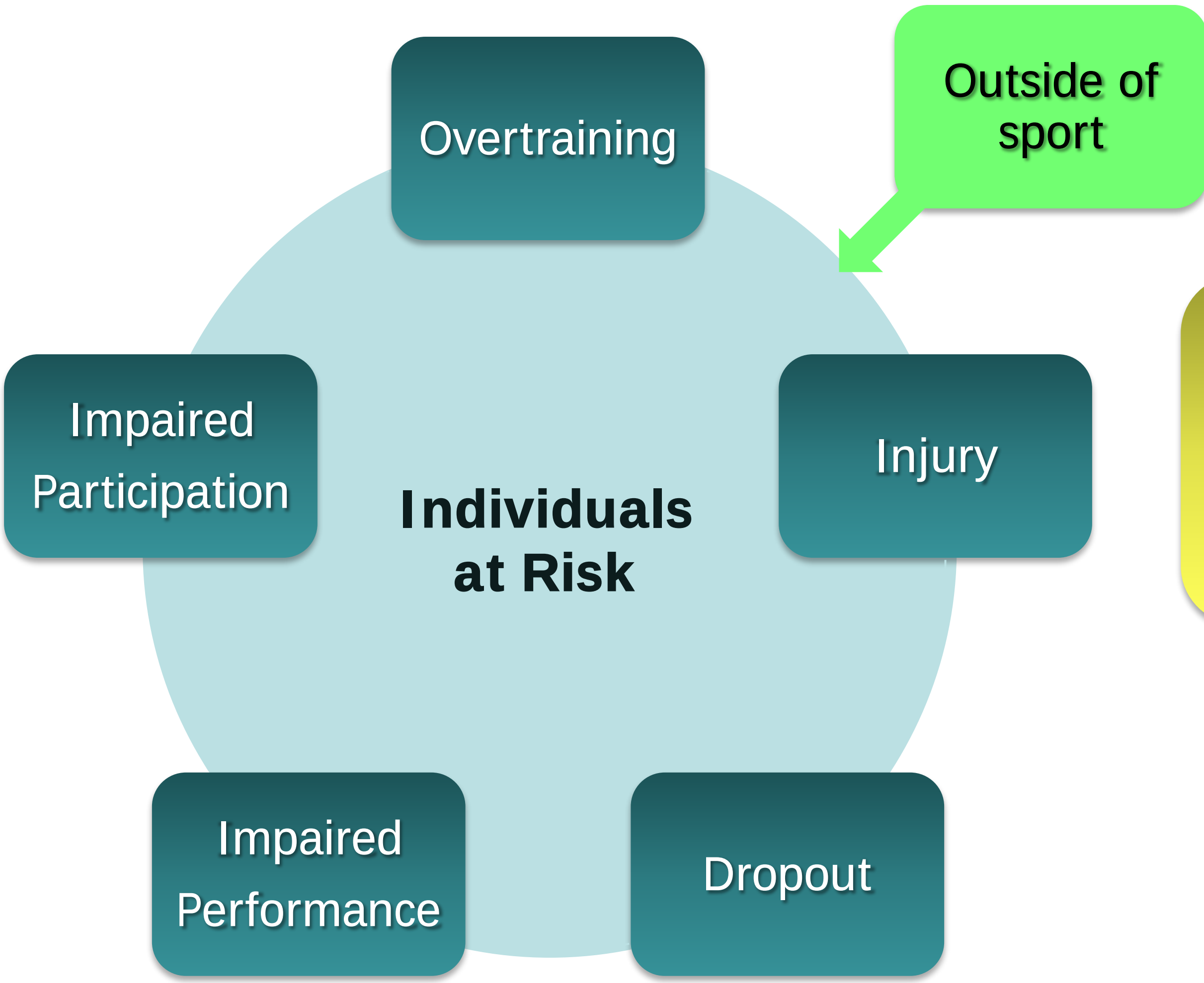
- **Trigger hypothesis: pubertal changes permissive for increased exercise capacity**
  - **Also abstract thinking and performance in tactical sports**

- **Nevertheless**
  - **trainability remains lower**
  - **glycogen stores + high energy phosphate kinetics?**
  - **movement efficiency?**

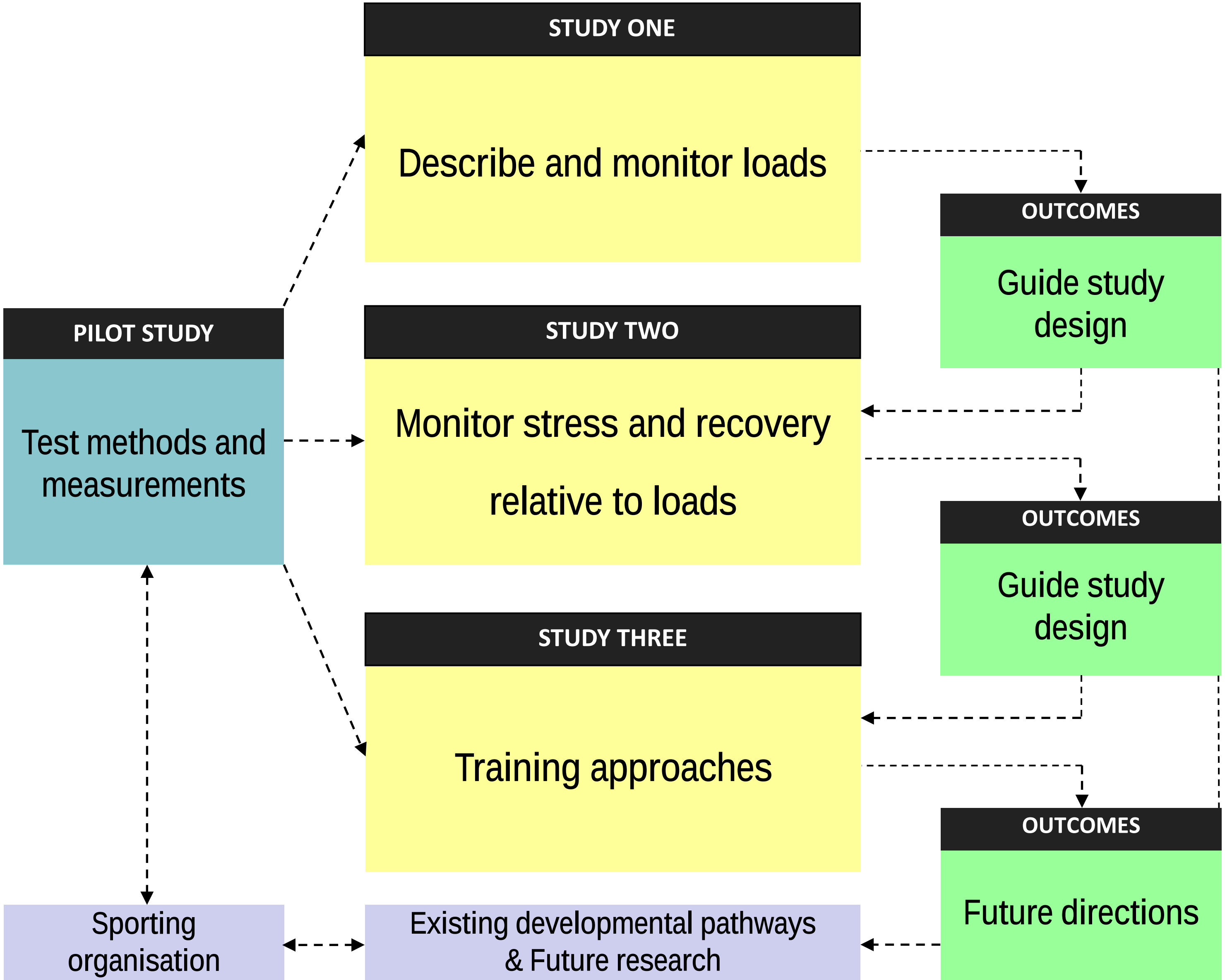
- **Unique psychosocial + physiological factors and stressors**

- **Loads or responses to loads may exceed individual adaptation thresholds**

Adolescent Maladaptation



Aim is to quantify and understand contributing factors, risks and consequences


STUDY ONE
Describe and monitor loads
PILOT STUDY
Test methods and measurements
STUDY TWO
Monitor stress and recovery relative to loads
OUTCOMES
Guide study design
OUTCOMES
Guide study design
STUDY THREE
Training approaches
OUTCOMES
Future directions
Sporting organisation
Existing developmental pathways & Future research

Study One

Defining the Volume and Intensity of Sport Participation in Adolescent Rugby Union Players

Timothy Hartwig[1], Geraldine Naughton[1], John Searl[2]

[1]Australian Catholic University, School of Exercise Science,
Centre of Physical Activity Across the Lifespan, Sydney, Australia,
[2]Australian Rugby Union, Sydney, Australia

International Journal of Sports Physiology and Performance, 2008, 3, 94-106.

Methods

75 players aged 14 to 18 years from three levels of rugby participation

School-Boy → Representative → Talent Squad

School-Boy	Representative	Talent Squad
(N=35)	(N=20)	(N=20)
12 weeks	6 weeks	10 weeks
105 hours	38 hours	44 hours

Participation Loads

Training Diaries

- Volume
- Intensity
- Type

Training Demands

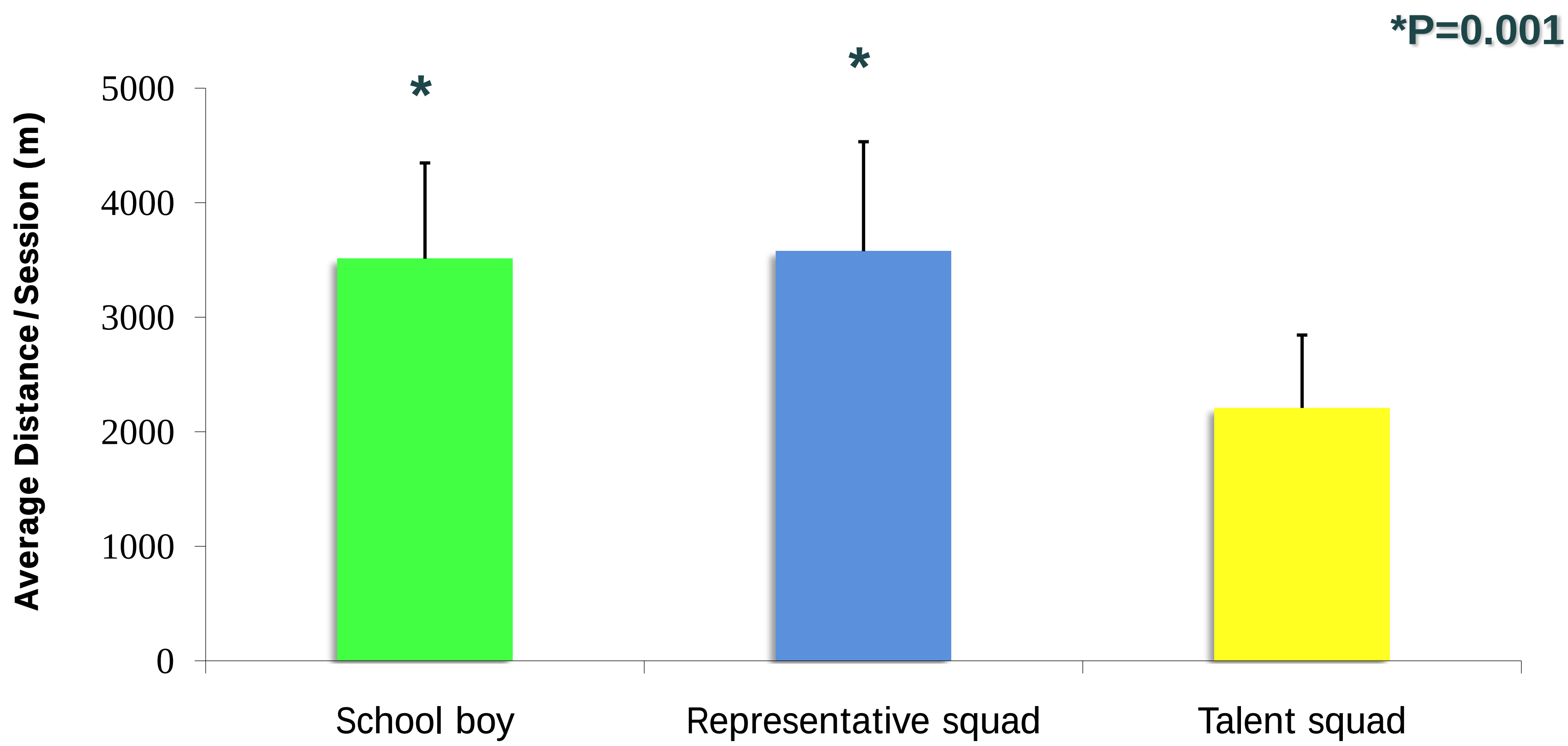
GPS

- Volume
- Intensity
- Type

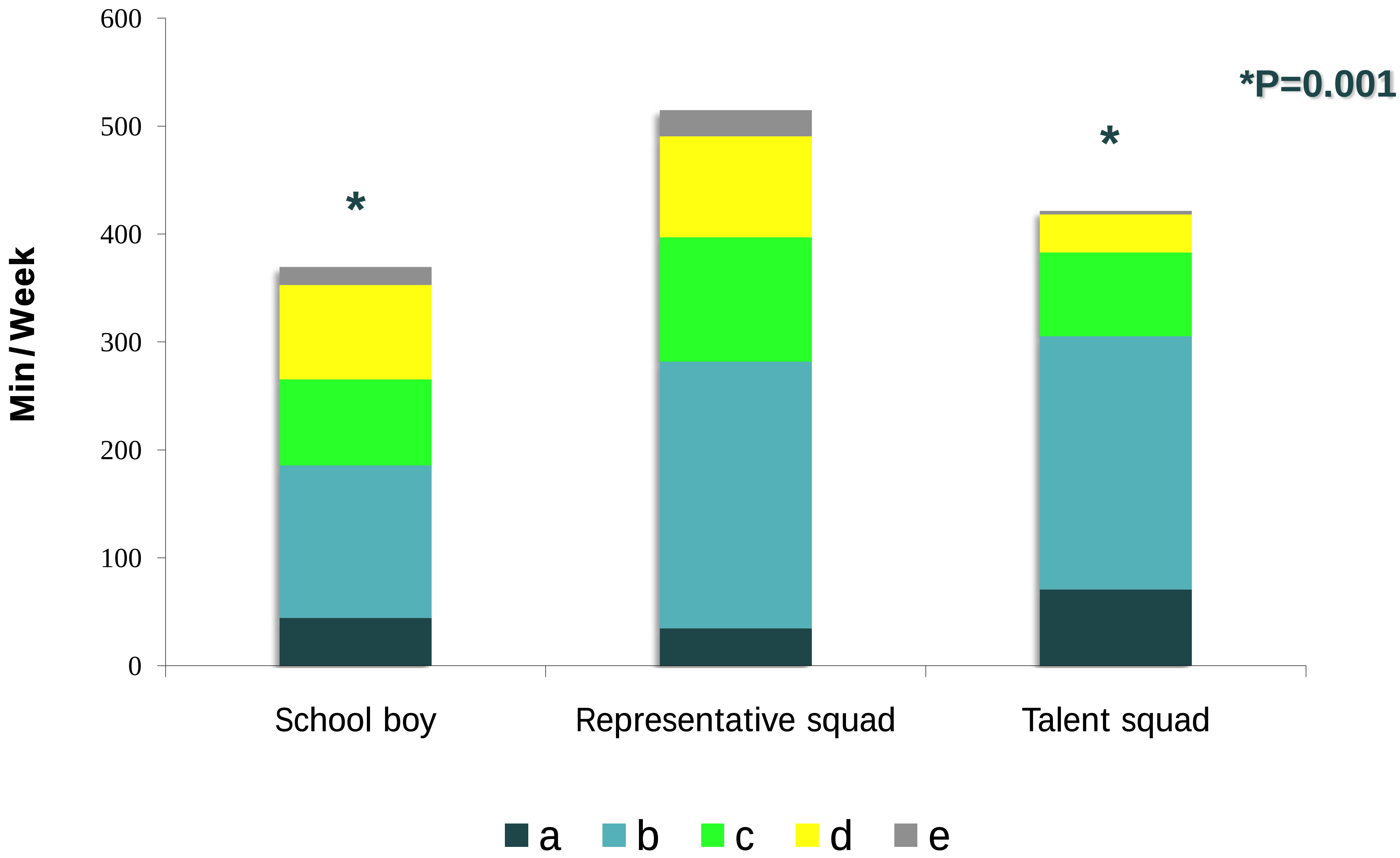
Statistical Analysis

- **Descriptive statistics**
- **One-way ANOVA**
- **Unadjusted Bonferroni post hoc analyses**
- **Significance was accepted at an alpha level of $P < 0.05$**

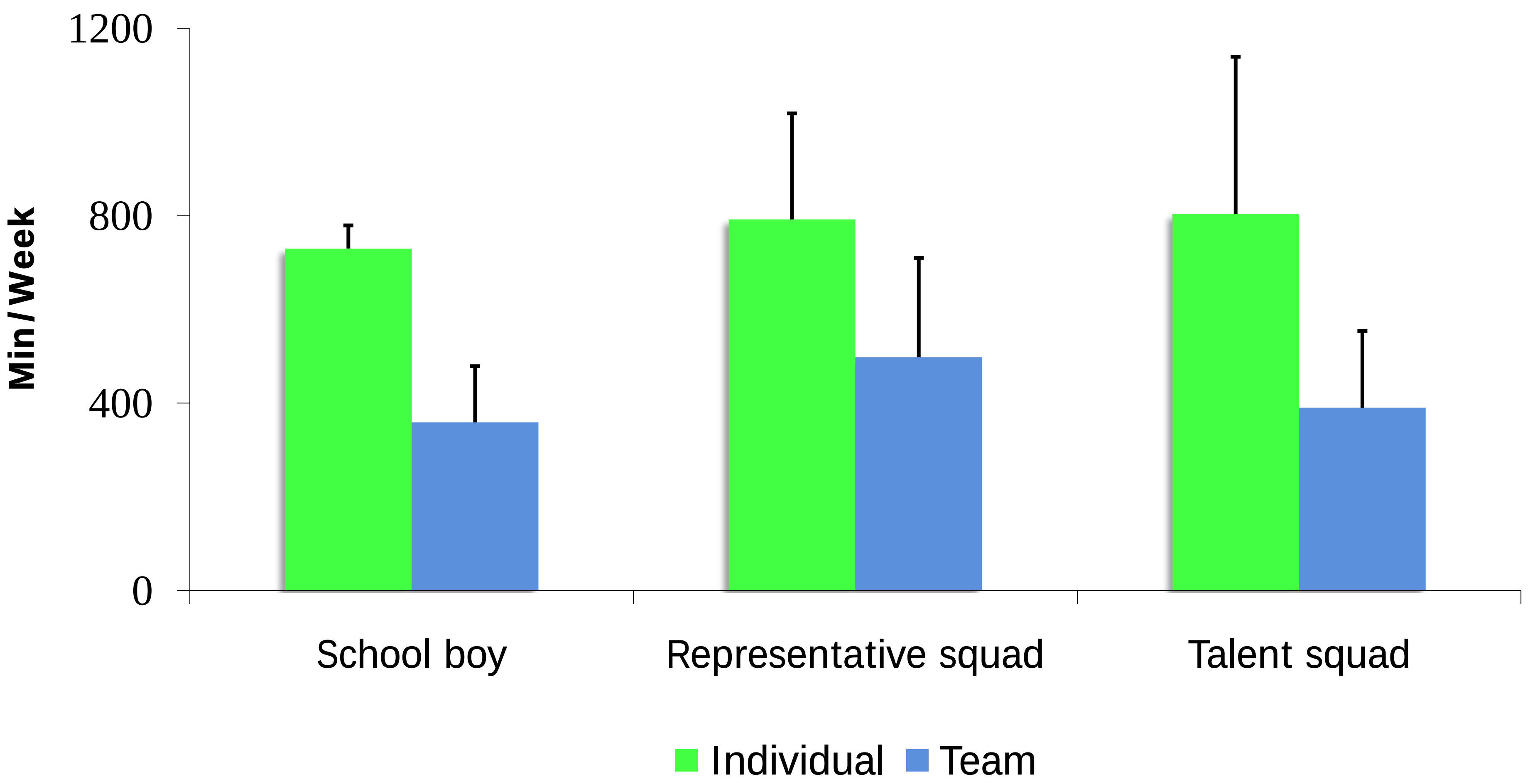
Rugby Training



Weekly Training



Individual Case Studies



Summary of Major Findings

- Multi-team, multi-sport participation
- Groups differed in time-motion measures during training
- Most talented team - lowest volume in training sessions
  - All teams on average <20% of time above 85%HRmax
- Weekly duration of all sports and physical activity appear high with large intra-team variability
  - Coutts 2007 (3100 & 5600AU), Brooks 2008 (7hrs/wk)
- High-effort players with up to 19 hours of weekly activity including as many as 3 games and 11 training sessions

australian RUGBY

Study Two

Load, Stress and Recovery in Adolescent Rugby Union Players During a Competitive Season

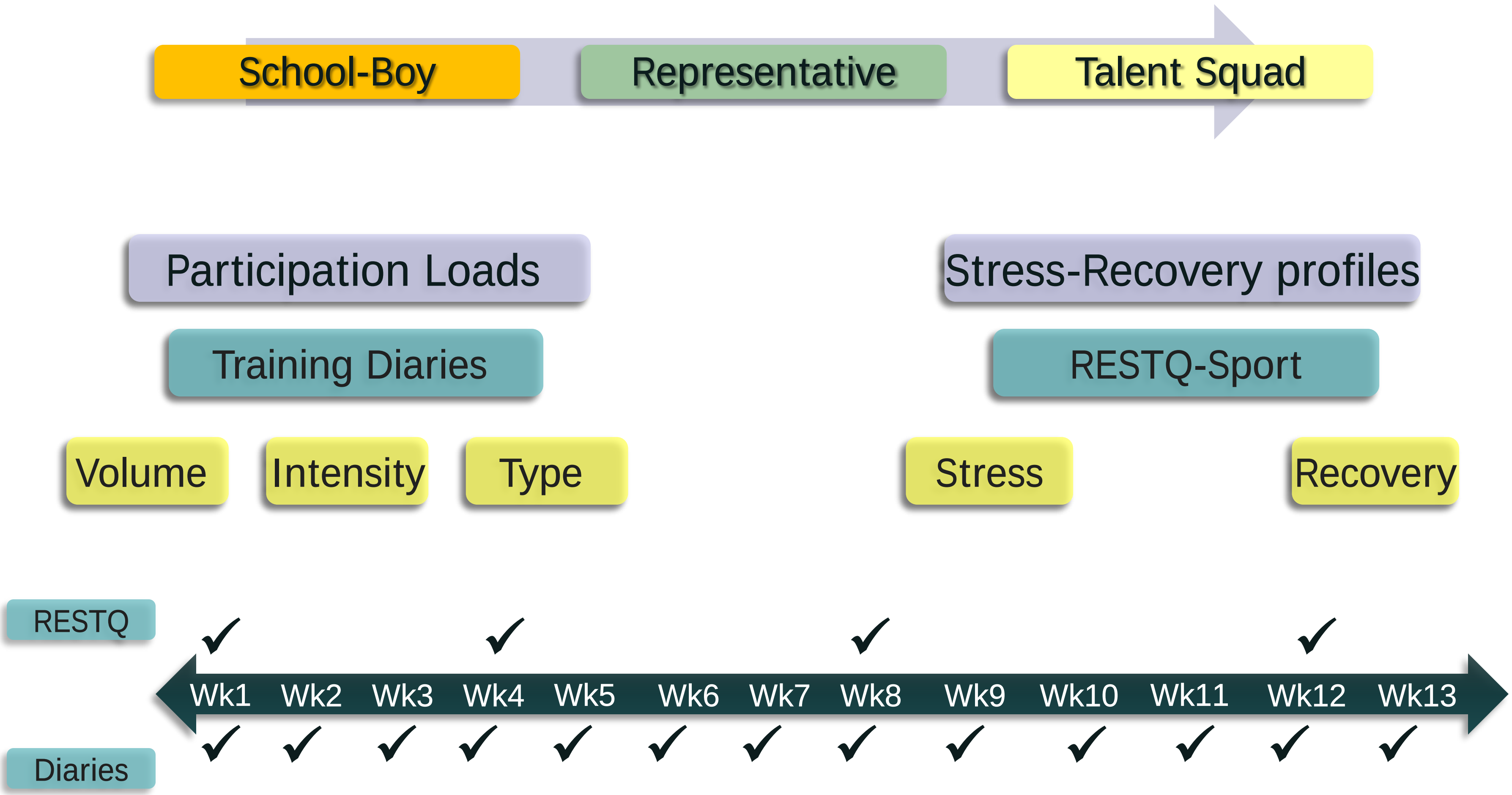
Timothy Hartwig[1], Geraldine Naughton[1], John Searl[2]

[1]Australian Catholic University, School of Exercise Science,
Centre of Physical Activity Across the Lifespan, Sydney, Australia,
[2]Australian Rugby Union, Sydney, Australia

Journal of Sports Sciences, 27 (10), 2009, 1087 – 1094.

Methods

121 male adolescent rugby union players aged 14-18 years



Statistical Analysis

- **Descriptive statistics**
- **One-way ANOVA (Unadjusted Bonferroni post hoc)**
- **Paired samples t-tests**
- **Significance was accepted at an alpha level of $P < 0.05$**
- **Data divided into tertiles and quintiles**

	School boy (N = 29)	Representative squad (N = 42)	Talent squad (N = 35)
Age (yr)	15.2 (± 0.6)	15.4 (± 0.7)	16.9 (± 1.5)
Height (cm)	177 (± 7)	179 (± 6)	177 (± 7)
Weight (kg)	72.7 (± 10.2)	86.5 (± 12.4)**	93.6 (± 13.2)**
Training Volume (hours)	6 (4 - 9)*	10 (4 - 17)	7 (3 - 13)*

Table 1 Descriptive and Training Data

*Significantly different from representative squad, $P < 0.001$
**Significantly different from school boy squad, $P < 0.001$.

RESTQ by Team

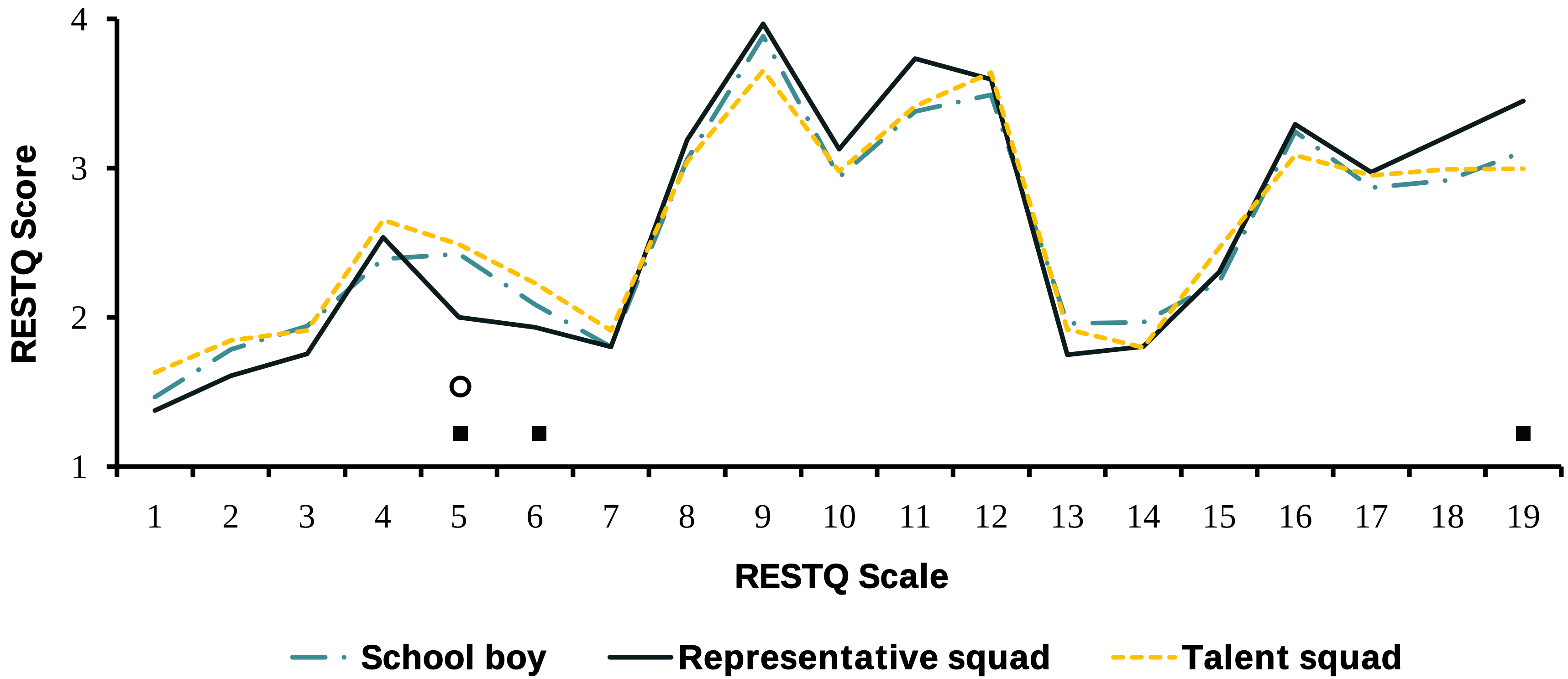


Figure 1 Mean scale scores for the RESTQ-Sport. °Significantly different between School boy and Representative squads. ▪Significantly different between Talent and Representative squads. 1-General Stress, 2-Emotional Stress, 3-Social Stress, 4-Conflicts/Pressure, 5-Fatigue, 6-Lack of Energy, 7-Physical Complaints, 8-Success, 9-Social Recovery, 10-Physical Recovery, 11-General Well-Being, 12-Sleep Quality, 13-Disturbed Breaks, 14-Burnout/Emotional Exhaustion, 15-Fitness/Injury, 16-Fitness/Being in Shape, 17-Burnout/Personal Accomplishment, 18-Self-Efficacy, 19-Self-Regulation.

RESTQ by Volume Tertiles

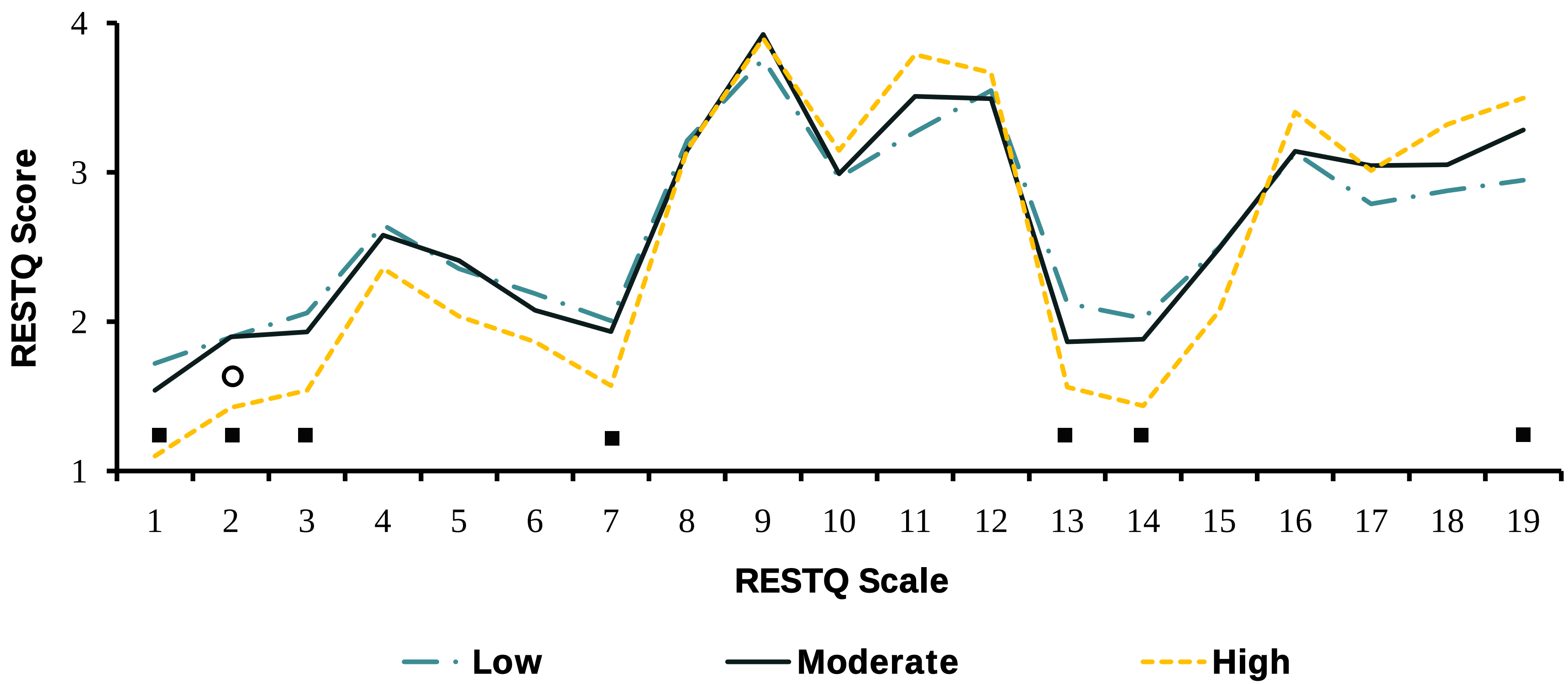
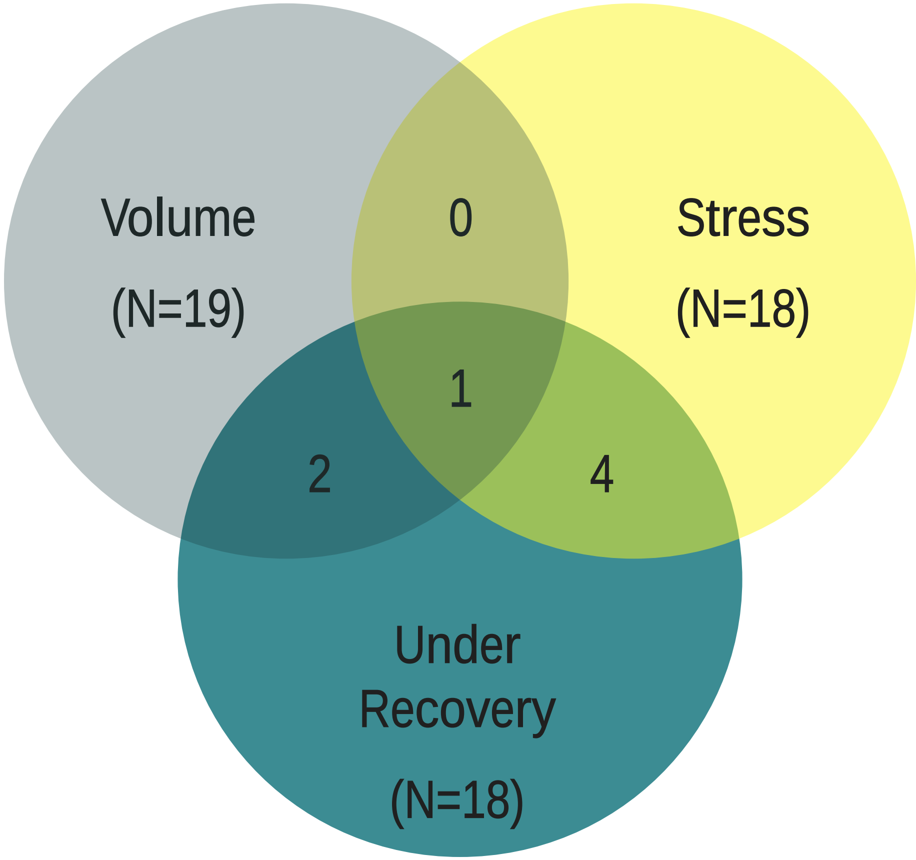


Figure 2 Mean scale scores for the RESTQ-Sport. °Significantly different between Moderate and High volume groups. ▪Significantly different between High and Low volume groups. 1-General Stress, 2-Emotional Stress, 3-Social Stress, 4-Conflicts/Pressure, 5-Fatigue, 6-Lack of Energy, 7-Physical Complaints, 8-Success, 9-Social Recovery, 10-Physical Recovery, 11-General Well-Being, 12-Sleep Quality, 13-Disturbed Breaks, 14-Burnout/Emotional Exhaustion, 15-Fitness/Injury, 16-Fitness/Being in Shape, 17-Burnout/Personal Accomplishment, 18-Self-Efficacy, 19-Self-Regulation.

Quintiled Individuals at Risk



Summary of Major Findings

- Few differences in psychological recovery-stress states with team comparisons
  - not different for global stress and recovery
- When grouped by volume, high volume players demonstrated more favourable recovery-stress states
- No seasonal change in volume effects on recovery-stress
  - Recovery decreased and stress increased over intensive periods
- Highest load, highest stressed and poorest recovered players revealed 'potential at risk individuals'

Study Three

Motion Analyses of Adolescent Rugby Union Players: A Comparison of Training and Game Demands

Timothy Hartwig[1], Geraldine Naughton[1], John Searl[2], Morgan Williams[1]

[1]Australian Catholic University, School of Exercise Science,
Centre of Physical Activity Across the Lifespan, Sydney, Australia,
[2]Australian Rugby Union, Sydney, Australia

Journal of Strength and Conditioning Research, 2009 (Under Review).

Methods

118 players aged 14 to 18 years from ten teams representing three levels of rugby participation

School-Boy → Representative → Talent Squad

Time-motion analyses performed on games and training sessions across portions of competition phase between 4 & 14 weeks

Training Demands

GPS

Volume | Intensity | Type

Game Demands

CBT

Volume | Intensity | Type

Statistical Analysis

- **Descriptive statistics**
- **Two-way mixed model ANOVA**
- **95% limits of agreement**
- **Significance was accepted at an alpha level of $P < 0.05$**

	Rugby Training	Rugby Games
Number of sessions observed	84	20
Number of hours analysed	187.8	32.9
Number of individual analyses*	161	53

Table 1 Total number of adolescent rugby union training sessions and games, number of hours analysed, and number of individual time-motion analyses.

GPS & CBT Method Agreement Study

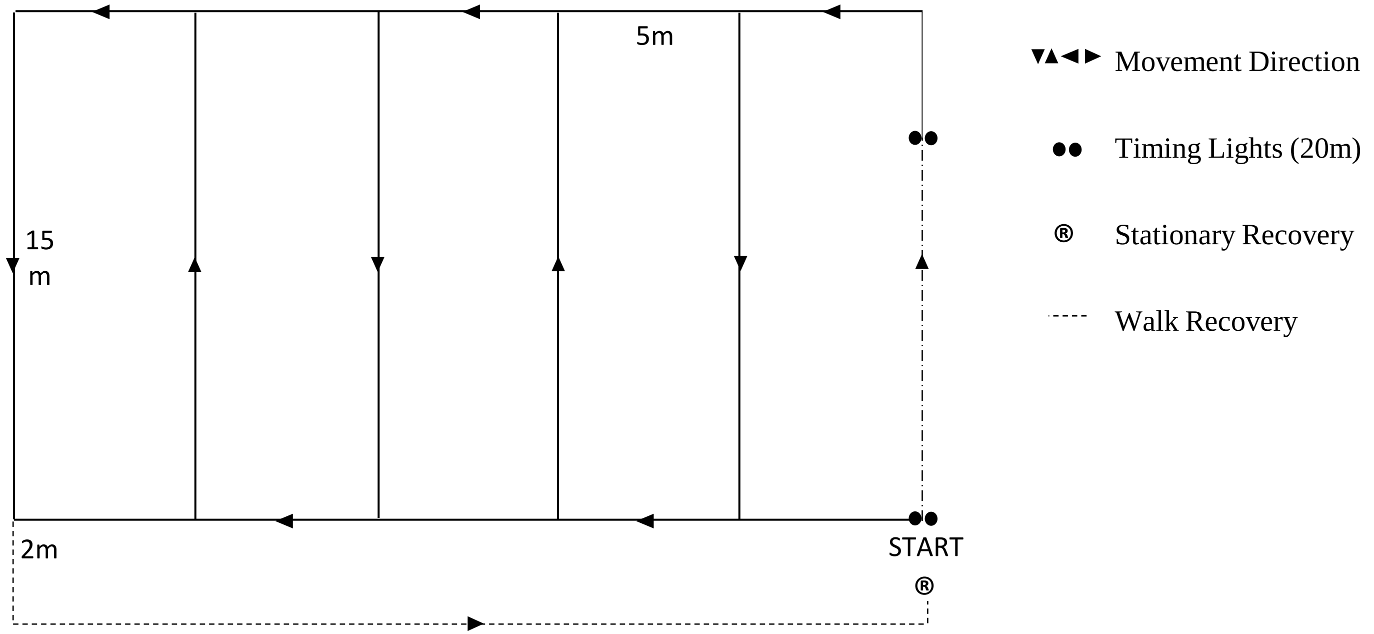
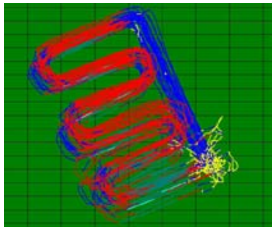


Figure Circuit test used to simulate typical player movement patterns .



	GPS	CBT
Total Distance (m)*	3973	4410
Percent Time Stationary (%)	39.9	40.8
Walk Distance (m)	1455	1543
Jog Distance (m)	1881	2071
High Intensity Run Distance (m)	567	768
Average 20m Sprint Velocity ($km.h^{-1}$)**	17.3	18.9

Table 3.1 GPS and CBT time-motion analyses results for circuit test (data are means for two participants measured using both GPS and CBT).

**Actual distance = 4320 m*
***Average 20 m sprint velocity determined using timing gates = 17.6 km.h-1*

Mean lap times measured using CBT and GPS, respectively were:

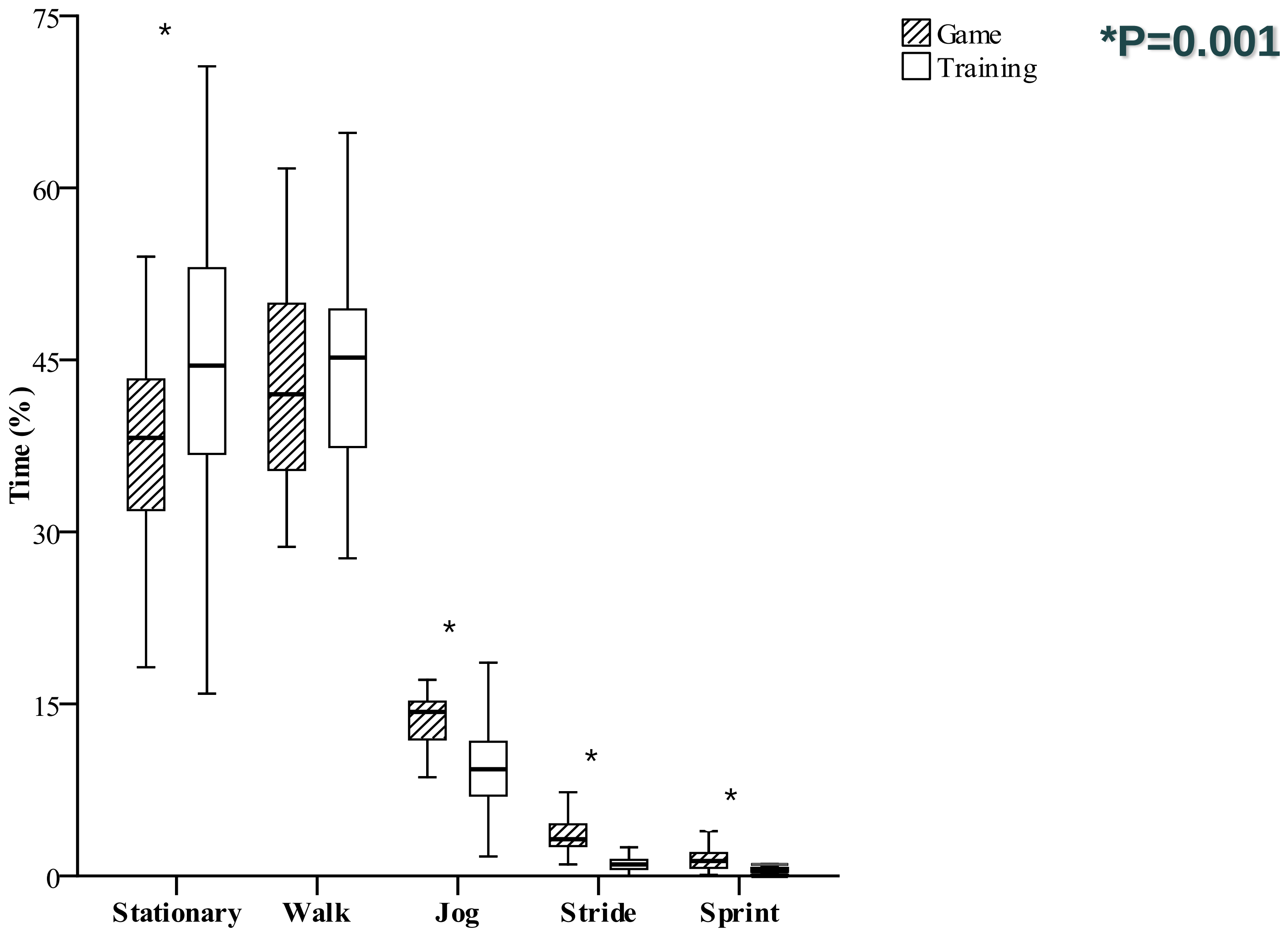
Stationary 48.9 and 47.6 s (LoA ± 5.4s)

Walk 38.6 and 41.8 s (LoA ± 8.9s)

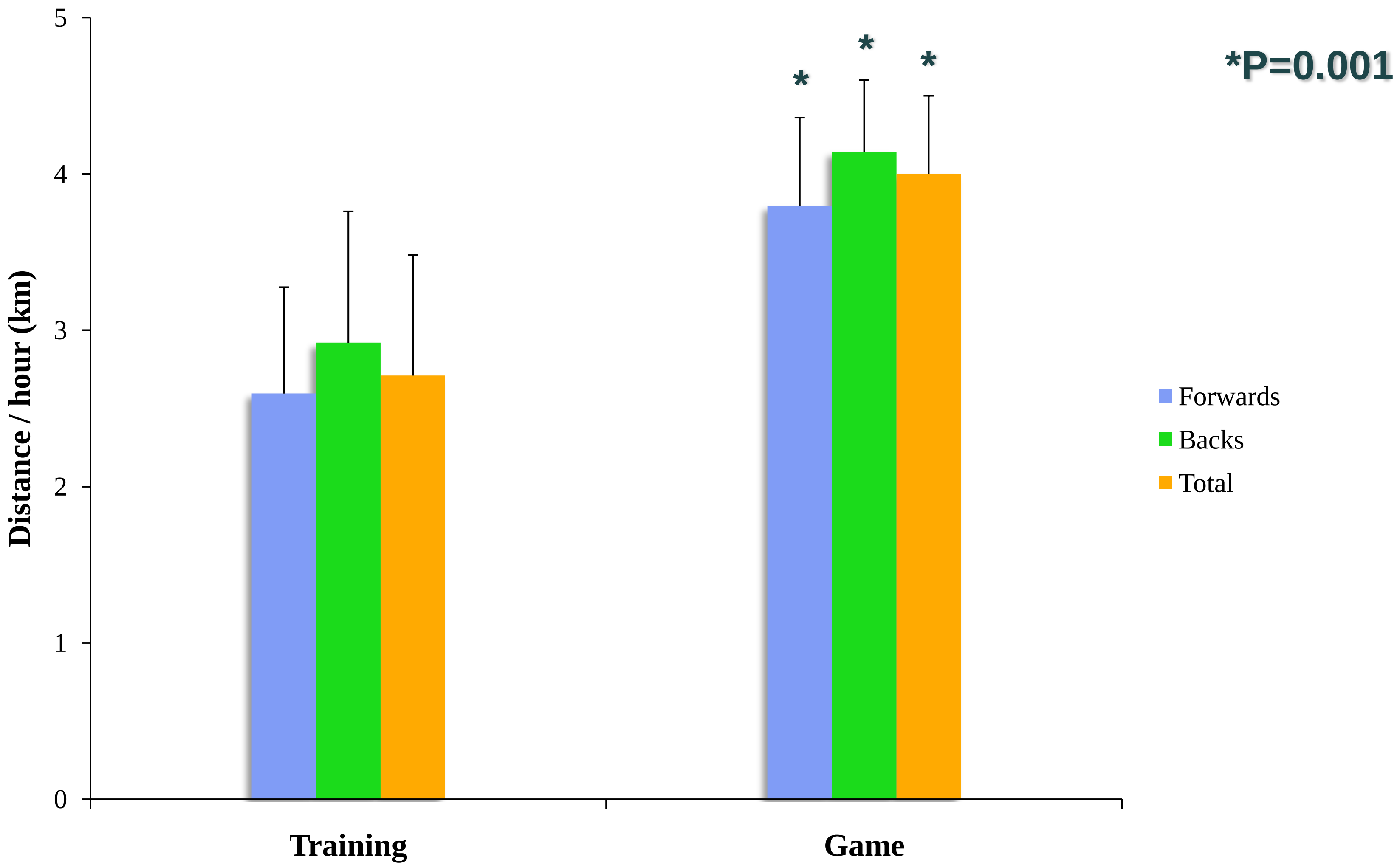
Jog 27.2 and 25.9 s (LoA ± 8.9s)

High intensity running 5.3 and 5.2 s (LoA ± 2.2s)

Game vs. Training



Game vs. Training



	Game (N=53)	Training (N=161)	Diff	p Value
Sprints/hour of play	21.8 (21.8) (2.9-84.6)	1.0 (3.8) (0.0-23.2)	20.8	<0.001
Sprint duration/hour of play (s)	45.0 (44.2) (2.9-160.3)	2.0 (7.6) (0.0-75.0)	43.0	<0.001
Sprint duration (s)	1.9 (0.6) (1.0-5.3)	2.0 (1.5) (1.0-5.2)	-0.1	0.350
Maximum sprint duration (s)	4.0 (3.0) (1.0-12.0)	3.0 (3.0) (1.0-14.0)	1.0	<0.001
Sprint distance/hour of play (m)	324 (319) (29-1141)	11 (43) (0-486)	313	<0.001
Sprint distance (m)	13.5 (5.0) (7.1-46.7)	11.7 (9.4) (3.0-39.3)	1.8	0.03

Table 2 Time-motion analysis data for game versus (interquartile range and range in parenthesis for non-parametric analyses). N=number of sessions analysed.

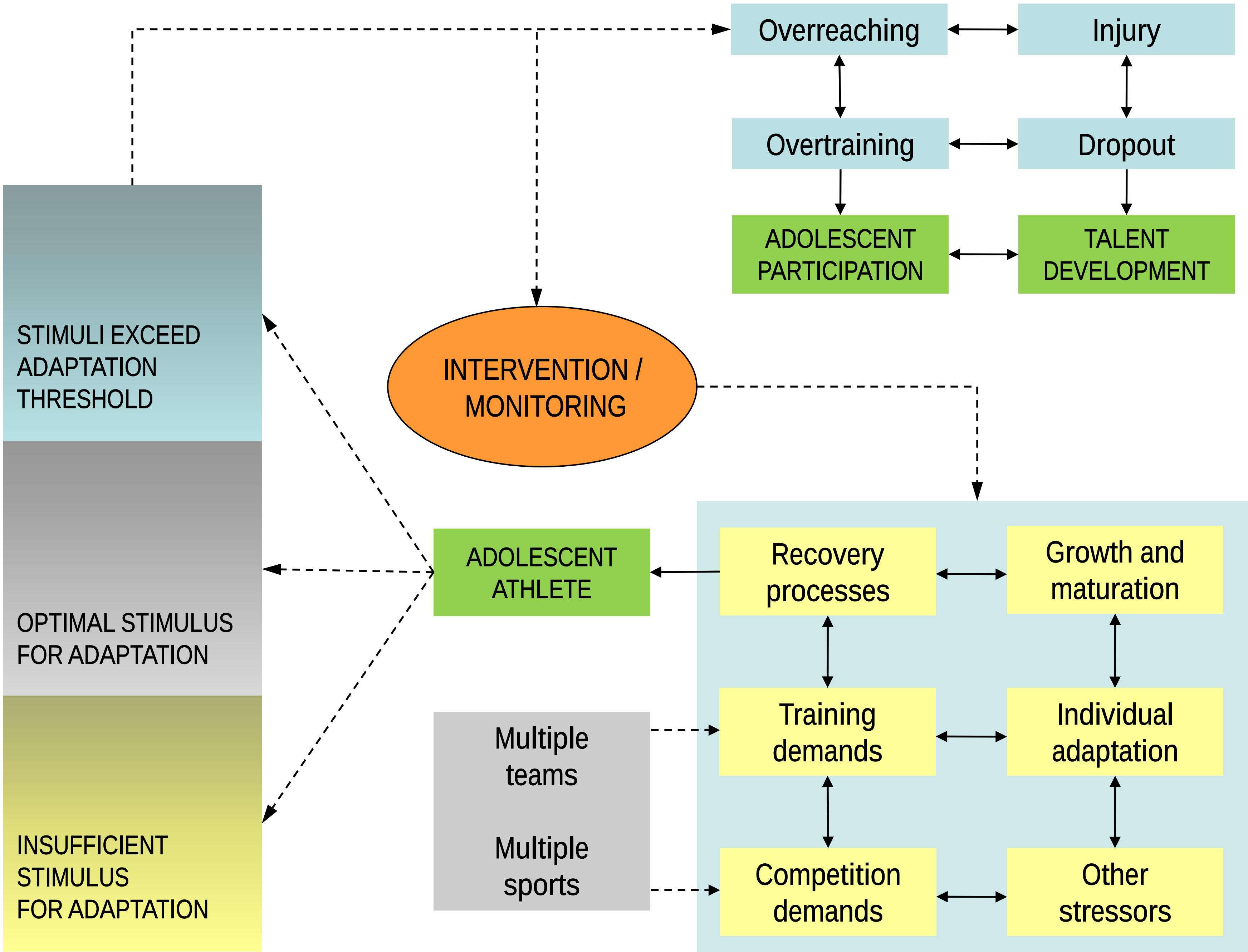
Summary of Major Findings

- **Training sessions lack specificity for physiological demands of games**
  - **distance covered**
  - **high intensity efforts**
  - **sprinting characteristics (RSA)**

- **Skill and tactical development may not be optimal**

- **Low intensity, high volume training**
  - **Contribution to high weekly loads and maladaptation + recovery?**

- **Descriptions of game and training demands useful for prescribing training and player development**
  - **Game-based training**



Overreaching
Injury
Overtraining
Dropout
ADOLESCENT PARTICIPATION
TALENT DEVELOPMENT
STIMULI EXCEED ADAPTATION THRESHOLD
INTERVENTION / MONITORING
OPTIMAL STIMULUS FOR ADAPTATION
ADOLESCENT ATHLETE
Recovery processes
Growth and maturation
Training demands
Individual adaptation
Multiple teams
Multiple sports
Competition demands
Other stressors
INSUFFICIENT STIMULUS FOR ADAPTATION

Conclusions

- **High loads among some players need to be addressed in future research, policy, and coach, parent and player education**
  - **Load monitoring**
- **Not all players demonstrated favourable capacities to deal with current participation loads**
  - **Monitor stress and recovery**
- **Multi-factorial monitoring systems could be sensitive to ‘red flagging’ at risk players**
- **Prevention is more desirable than detection at any stage**
  - **Developmental pathways**
- **Since coaches play a critical role in athlete development, coach quality is fundamental**
- **Determining optimum approaches in teams sports remains a major challenge**