Physiological and psychological characteristics of elite female adolescent athletes

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PHYSIOLOGICAL AND PSYCHOLOGICAL CHARACTERISTICS OF ELITE FEMALE ADOLESCENT ATHLETES

By

Persephone Wynn

A Doctoral Thesis

Submitted in partial fulfilment of the requirements for the award of Doctor of Philosophy of Loughborough University

January 2009

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Abstract

ABSTRACT

This thesis examined the physiological and psychological characteristics of elite female adolescent athletes compared to non-elite female adolescent athletes in relation to age and maturity.

In Chapter 4 the maturation and body composition of eighty six elite and one hundred non-elite adolescent female athletes between the ages of 12 and 17 years was examined. Stature, body mass, age of onset of menarche, age of onset of maternal menarche, sexual maturity, sum of circumferences, sum of 7, 4 and 2 skinfolds, and estimated percentage body fat were compared. There were no significant differences between the elite and non-elite athletes for either stature or body mass. The elite athletes recorded a later onset of menarche than the non-elite athletes ($P<0.05$). The mothers of the elite athletes recorded a later onset of menarche than the mothers of the non-elite athletes ($P<0.05$). Maturation stage, as defined by Tanners' indices for pubic hair was lower in elite athletes for all age groups except 16 years ($P<0.01$). Maturation stage as defined by Tanners' indices for breast development showed a tendency to be less pronounced in the elite athletes for all age groups except 15 and 16 years ($P=0.08$). The elite girls had a lower sum of all circumferences ($P<0.01$), a lower sum of 4 skinfolds ($P<0.01$) and a lower estimated percentage of body fat ($P<0.01$) in all age groups. The elite girls had a larger thigh circumference ($P<0.05$) when analysed by maturation stage, than the non-elite girls. The results suggest that the elite girls were less fat, had more muscular legs, but smaller overall circumferences than the non-elite girls. The elite girls had a later onset of menarche and showed correspondingly lower stages of maturation than the non-elite girls. The image of the young female elite athlete from this study is of a girl with a lean muscular physique who is a late maturer.

In Chapter 5 the responses to treadmill running in eighty six elite and one hundred non-elite adolescent female athletes between the ages of 12 and 17 years were examined. The elite athletes had higher $\dot{V}O_2$ peak (l.min$^{-1}$) and (ml.kg$^{-1}$.min$^{-1}$) and lower maximum heart rates (beats.min$^{-1}$) than the non-elite athletes ($P<0.01$) and there was an effect of maturation and age for $\dot{V}O_2$ peak (l.min$^{-1}$). When performing the submaximal treadmill running test the elite athletes were less economical than the non-elite athletes ($P<0.01$) when analysed by age but when maturity was taken into account there were no differences between the groups. Blood lactate concentration, heart rate, rate of perceived exertion and R value were all lower in the elite athletes than in the non-elite athletes ($P<0.01$) with no effect of either age or maturation for blood lactate concentration but an effect of age and maturation for heart rate, rate of perceived exertion and R value. The elite athletes ran at a lower percentage of their maximum heart rate ($P<0.01$) than the non-elite athletes and there was a main effect of maturation and age.

In Chapter 6 power output during and blood lactate concentration following a 30 s maximal cycle sprint and upper and lower body and strength measures in elite and non-elite female adolescent athletes were examined. Eighty six elite and one hundred non-elite adolescent female athletes between the ages of 12 and 17 years performed a 30 s maximal cycle sprint and strength measures on a Concept2 Dyno®. There were no
differences between the elite and non-elite athletes for peak power output (W and W.kg\(^{-1}\)) when examined by age or by maturity. However, mean power output (W and W.kg\(^{-1}\)) was higher in the elite athletes than the non-elite athletes when analysed by age (P<0.01) and maturity (P<0.01). The fatigue index was lower for elite than non-elite (P<0.01), indicating better endurance in the elite athletes but blood lactate concentrations post-sprint were similar for both groups. The elite athletes were stronger than the non-elite athletes in combined leg press (P<0.01), left leg press (P<0.05) and arm press (P<0.01) but right leg press and arm pull were similar for both groups. Maturation had an independent effect on both power and strength.

In Chapter 7 the psychological makeup of the elite female adolescent athlete was examined. Sixty six elite female adolescent athletes and sixty one non-elite female adolescent athletes participated in the study. The Test of Performance Strategies (TOPS) identified that the elite girls used the constructs of ‘imagery’ (P<0.01) and ‘attentional control’ (P<0.01) in practice, and the constructs of ‘goal-setting’ (P<0.01) and ‘activation’ (P<0.05) in competition significantly more than the non-elite girls. The Individual Sport Motivated Climate Scales (ISMCS) identified that the elite girls felt that their coaches’ were significantly more likely to have or use ‘task involving behaviours’ (P<0.05), ‘ego involving behaviours’ (P<0.01), and ‘task involving values/attitudes’ (P<0.05) than did the non-elite girls. The ISMCS identified that elite girls felt that their fathers’ were more likely to have or use ‘ego involving values’ (P<0.01), ‘task involving values’ (P<0.01) and to have a ‘positive affective style of reinforcement’ (P<0.05) than did the non-elite girls. When the mother section of the ISMCS was examined it found that the elite girls felt that their mothers’ were more likely to have ‘ego involving values’ (P<0.01) than did the non-elite girls. The ISMCS scales for peers showed that the elite girls had a tendency (P=0.051) to feel that their peers would be more likely to have ‘task involving values and behaviours’ than did the non-elite girls. The ISMCS showed that the elite athletes were significantly more likely (P<0.01) to record ‘influence from significant others and the sporting reward structure’ than were the non-elite athletes. There were no significant differences between the groups for the psychological instrument Beliefs About the causes of Success Questionnaire’ (BASQ) or for the psychological instrument ‘Perceptions of Success Questionnaire’ (POSQ). The psychological instrument, Situational Motivational Scale (SIMS) identified that the elite athletes were significantly more likely (P<0.01) to record ‘influence from significant others and the sporting reward structure’ than were the non-elite athletes. There were no significant differences between the groups for the psychological instrument Beliefs About the causes of Success Questionnaire’ (BASQ) or for the psychological instrument ‘Perceptions of Success Questionnaire’ (POSQ). The psychological instrument, Situational Motivational Scale (SIMS) identified that the elite athletes were less likely (P<0.05) to be highly intrinsically motivated for their sport participation than the non-elite athletes.

In Chapter 8 a longitudinal analysis of eighty six elite and 100 non-elite adolescent female athletes between the ages of 12 and 17 years was conducted using multilevel additive regression modelling. The Binomial Logistical Regression analysis of the data revealed that the key explanatory variables that distinguish elite female adolescent athletes from non-elite female adolescent athletes are \(\dot{V}O_2\) peak (ml.kg\(^{-1}\).min\(^{-1}\)), Maximum Heart Rate (beats.min\(^{-1}\)), Arm Push Strength (kg) and Blood Lactate Concentration (mmol.l\(^{-1}\)) at 9 km.h\(^{-1}\). The elite athletes had higher \(\dot{V}O_2\) peak (ml.kg\(^{-1}\).min\(^{-1}\)) and \(\dot{V}O_2\) peak (l.min\(^{-1}\)) (P<0.05). The elite athletes had lower heart rates (beats.min\(^{-1}\)), ran at lower percentages of their maximum heart rates and had lower blood lactate concentrations (mmol.l\(^{-1}\)) when performing submaximal treadmill running at 9.0 km.h\(^{-1}\) than the non-elite athletes (P<0.05). There was a negative effect of 

\[ \text{sum} \]
of 4 skinfolds for \( \dot{\text{VO}}_2 \) peak (ml.kg\(^{-1}\)min\(^{-1}\)) showing that as skinfold values increased \( \dot{\text{VO}}_2 \) peak decreases (P<0.05). There was an independent effect of maturity for \( \dot{\text{VO}}_2 \) peak (ml.kg\(^{-1}\)min\(^{-1}\)) and \( \dot{\text{VO}}_2 \) peak (l.min\(^{-1}\)) (P<0.05). Peak and mean power output (W and W.kg\(^{-1}\)) following a 30 s maximal cycle ergometer sprint were similar for both groups. There were positive independent effects for age, maturation at pubic hair stage 4/5, and body mass, and negative effect of sum of skinfolds (P<0.05). Combined leg press was similar between the groups, though there was an independent effect of body mass and a negative effect of sum of skinfolds (P<0.05). Arm press and arm pull strength were both higher in the elite than the non-elite female adolescent athletes (P<0.05), with additive independent effects of upper arm circumference and body mass (P<0.05)

Summary

The elite female adolescent athletes in this study were late maturers and had a later onset of menarche than the non-elite female adolescent athletes. They had less adipose tissue and more muscle than the non-elite athletes, though they were similar in height and body mass. The elite athletes had higher \( \dot{\text{VO}}_2 \) peak (l.min\(^{-1}\)) and lower maximum heart rates (beat.min\(^{-1}\)) when analysed by age and maturation status. \( \dot{\text{VO}}_2 \) peak (ml.kg\(^{-1}\)min\(^{-1}\)) was higher in the elite athletes but there was no effect of age or maturation. The elite athletes were less economical than the non-elite athletes during submaximal running, yet had lower blood lactate concentrations (mmol.l\(^{-1}\)), lower heart rates (beats.min\(^{-1}\)), worked at a lower percentage of their maximum heart rates, reported lower rates of perceived exertion and had lower R values. During the 30 s cycle maximal sprint the groups were similar for peak power (W) but there were independent effects of age and maturation. The elite girls had higher mean power output (W and W.kg\(^{-1}\)). Blood lactate concentrations were similar for both groups though there was an independent effect of age and maturation. The elite athletes had higher combined leg press, higher left leg press and higher arm press than the non-elite athletes. There was an independent effect of age and maturation power and strength. The elite athletes were more skilled at using psychological strategies in training and competition and perceived that the significant others around them were both task and ego oriented with regards to their sporting success.
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CHAPTER 1

Introduction

Talent identification in sport in the form of selection of local, regional, and national age-group squads is occurring at ever younger ages. For example, at Loughborough University, the Loughborough Tennis Academy encourages young players who are perceived to have excellent potential to move to full-time training between the ages of 9 – 12 years for girls and 10 – 13 years for boys. However, the success rate in terms of progression from junior to senior, as evidenced by the lack of outstanding senior international British players, is relatively poor. One of the possible causes for this apparent lack of success is that little is known about the physiological and psychological characteristics of young people that will lead to future international success. The fact that selection takes place during puberty is a confounding factor. In boys, it is known that early maturers dominate junior regional and national age-group squads in sports such as swimming and tennis (Baxter-Jones et al., 1995). If more was known about the physiology and psychology of the young people and the confounding influence of maturation on these variables it might enable the selection of more appropriate young people who may then progress to senior international status, thus eliminating the disappointment that comes from having been mistakenly identified as having elite senior potential at a very young age.

In particular, there is a dearth of information with respect to the physiology and psychology of the elite female adolescent athlete. The few studies on the adolescent elite female athlete have focused on injury (Nash, 1987), the effect of physical activity on maturation and the age of onset of menarche (Bass et al., 2002; Klentrou and Plyley, 2003; Vadocz et al., 2002), the effect of physical activity on body composition (Damsgaard et al., 2001), nutritional status (Filaire and Lac, 2002; Frisch, 1996), the effect of exercise on puberty and growth (Georgopoulos et al., 1999; Warren, 1980), and the effect of growth on heart and lung function (Andrew et al., 1972; Hopper et al., 1991). Thus when trying to determine the factors which contribute to success or progression in sport researchers have relied largely on studies with a male subject base.
Chapter 1

Introduction

Maturity is one factor that has been shown to influence progression in sport. The effect of intense training on the growth and development of young elite male gymnasts was investigated in a cohort of Canadian boys (n=21, aged 13.3 ± 0.3 y) who were all training for at least 15 hours a week (Gurd and Klentrou, 2003). Whilst the elite boys had very low percentage of body fat in comparison with the non-elite boys there were no other significant differences between the two groups, indicating that the intensive training undertaken by young elite male gymnasts did not impact on their growth and maturation adversely (Gurd and Klentrou, 2003). Similarly, Malina (1994b), found that there were no differences in size, age at peak height velocity, and peak height velocity between active and inactive boys from Canada and Belgium. Polish and Czech boys who were involved in (mostly) team sport were consistently taller than the available reference data and were taller than the boys who were not as involved in sport and also attained peak height velocity at a younger age. The Polish and Czech boys’ growth pattern was characteristic of early maturing males (Malina, 1994b). Selection into adolescent sports teams is often based partly on physical characteristics such as size, height, body mass and tends to favour early maturers. Whether selection depends more on the physical and physiological characteristics of an athlete is a question that Baxter-Jones et al., (1995) attempted to answer in a large (n=232) group of male athletes who were followed for 3 years. The athletes were all part of the TOYA study and were randomly selected from their age group in elite level junior soccer, gymnastics, swimming, and tennis. The swimmers were found to be more sexually mature and taller than the gymnasts or the soccer players and heavier than the gymnasts, soccer players, and the tennis players. When compared to the standard growth charts male swimmers were tall for their age, as were the tennis players, whilst the gymnasts were small for their age. All of the young athletes commenced training in their sport prior to puberty which suggested that the observed early maturation of the swimmers and the late maturation of the gymnasts was due to some type of sport-specific selection on the basis of genetic predisposition rather than due to effect of training per se (Baxter-Jones et al., 1993).

In contrast to the tendency for early maturity of elite male adolescent athletes, female athletes who commence training at a young age often have a delayed menarche, with genetic factors playing a part in the timing of the onset of menarche (Kaprio, et al. in
Klentrou and Plyley (2003). Girls who mature later, often appear to self-select sports requiring a high relative strength and small bodies, i.e. artistic gymnastics (Klentrou and Plyley, 2003). Earlier puberty was found to be significantly associated with early menarche in the mothers of adolescent Danish girls (n=96) competing in swimming, tennis and team handball at regional and national competition (not stated to be elite level), whereas the girls in gymnastics were less advanced in terms of maturity (Damsgaard et al., 2001). It was also found that the girl swimmers (n=28) were earlier in their pubertal status than were the girl gymnasts (n=32) (Damsgaard et al., 2001). The age that their mothers’ attained menarche was also significantly associated with the athlete’s breast development (P<0.01) (Damsgaard et al., 2001). It has been reported that girls who excel in athletics tend to have a more linear physique than the general female population, and girls with linear physiques also tend to have a later menarche (Claessens et al., 2003). Thus, the female adolescent athlete appears to mature later in some sports such as gymnastics, but for other sports the maturity status is unclear due to an inadequate number and quality of published papers.

Aerobic power also contributes to sporting performance and progression. The development of aerobic power (peak \( \text{VO}_2 \)) in young elite male athletes has been found to be significantly related to physical growth (age, body mass and height) and pubertal development (Baxter-Jones et al., 1993). In adolescents there is a clear increase of peak \( \text{VO}_2 \) during growth and maturation that is not purely attributable to any training or regular physical activity that the young person may participate in (Geithner et al., 2004). However, before the age of peak height velocity, there does not appear to be a significant increase in peak \( \text{VO}_2 \) (l.min\(^{-1}\)) as a result of training (Kobayashi et al., 1978), though a large increase occurred during the adolescent growth spurt although peak \( \text{VO}_2 \) (l.min\(^{-1}\)) increases with size as might be expected. Kobayashi et al. (1978) found that training effectively increased aerobic power (l.min\(^{-1}\)) in Japanese schoolboys and trained elite runners from about one year prior to peak height velocity and thereafter. These findings were confirmed by Mirwald et al., (1981) who found that there were no significant differences in aerobic power (l.min\(^{-1}\)) before what they describe as the adolescent growth spurt, in two groups of boys, active and inactive but that the active boys attained significantly higher aerobic power than the inactive boys by
the age of peak adolescent velocity in aerobic power, the increase from take-off to peak and in the adult value. Mirwald et al (1981) concluded that

"adolescence is the critical period during which consistently higher rates of increase in the VO\textsubscript{2max} of active boys result in a significantly greater adult value" (Mirwald et al., 1981)

In females, Geithner et al. (2004) found that growth spurts in height, body mass and peak VO\textsubscript{2} occurred earlier in females than in males and that the magnitude of the changes was less in the females. Malina et al. (2004b pp 242-43) found that VO\textsubscript{2} max in girls increased until around 13 years of age and then plateaued off for the remainder of adolescence. However Armstrong and Welsman (1994) conducted a meta-analysis of almost 5000 treadmill determined VO\textsubscript{2peak} scores collected from untrained children and adolescents aged between 8 and 16 years of age during the years 1938-1993 and found that there was an almost linear increase in peak VO\textsubscript{2} with age in both boys and girls. Only one study (Van Huss et al., 1988) has compared directly the aerobic power of elite and non-elite adolescent athletes and, with a small number of subjects, found aerobic power to be higher in elite athletes. Thus there is a need for further work investigating aerobic power in the elite adolescent athlete and the contribution of aerobic power to success and progression in sport.

The term running economy is used to express the oxygen uptake needed to run at a given velocity and is the ratio of work done to energy expended (Bassett and Howley, 2000). An early study of males and females over a range of ages (4 – 33 years) clearly showed that youngsters were less economical than adults when running (Åstrand, 1952). Åstrand explained that even though the younger boys had an equally high VO\textsubscript{2} max (ml.kg\textsuperscript{-1}.min\textsuperscript{-1}) as the more mature boys, they were less ‘efficient’ and therefore could not run as fast (Åstrand, 1952). Åstrand noted that steady state submaximal VO\textsubscript{2} (ml.kg\textsuperscript{-1}.min\textsuperscript{-1}) at any given running speed fell steadily with age, suggesting that children become more economical as they get older (Åstrand, 1952). Sjödin and Svedenhag (1992) investigated the effects of endurance training during growth on young male runners (n=8) aged 12 years at the start of the study, for 8 years. Four untrained boys of the same age acted as controls. Maximal oxygen uptake (VO\textsubscript{2} max [
ml.kg\(^{-1}\).min\(^{-1}\)) decreased with growth in the untrained boys, but remained almost constant in the boys who were training. The oxygen cost of running at 15 km.h\(^{-1}\) (\(\overline{V}O_2\) \(15\ [ml.kg^{-1}.min^{-1}]\)) was persistently lower in the training group, but decreased similarly with age in both the training and non-training boys. The development of \(\overline{V}O_2\)max and running economy was directly related to the increase in body mass of each individual boy. The trained group also increased the running velocity that corresponded to a blood lactate concentration of 4 mmol.l\(^{-1}\), but blood lactate concentration at exhaustion remained the same in both groups during the years they were studied (Sjödin and Svedenhag, 1992). Thus, while it has been shown that running economy is enhanced in the male elite adolescent athlete, the running economy of the elite female adolescent athlete has not been examined.

Speed and power may be important factors in determining performance for the elite adolescent athlete, but there have been few studies examining these variables. Short-term power during cycle ergometer sprinting was examined in elite 11 year old gymnasts, handball and tennis players (Bencke et al., 2002). While power was higher for elite than non-elite, when normalised for body mass there were no differences. There was no independent effect of maturation. However, Hemmings (2006 pp 135 - 152 unpublished thesis) investigated the power output in elite and non-elite adolescent males and females and found that ratio scaled peak power was significantly higher and absolute peak power was nearly, but not significantly, higher in the elite males when compared by age, but when compared by maturity only ratio scaled peak power showed a trend toward higher values in elite male adolescent athletes. In elite female adolescent athletes absolute peak power, and both absolute and relative mean power values were lower for elite females aged 13 years, but then higher for subsequent ages when compared to non-elite females (Hemmings, 2006). Therefore it would appear that peak power output in elite female adolescent athletes whilst strongly influenced by maturation and age, may also be affected by training.

Strength is another factor which may influence progression and success in sport. There is a fairly linear increase in static strength in boys that follows chronological age from the age of 6 years until around 12 to 13 years when a marked acceleration occurs through to the late teens (Beunen and Thomis, 2000). In boys the adolescent spurt in
strength starts around 1.5 years before peak height velocity and reaches a peak about 0.5 years after peak height velocity. Early maturing boys aged 11 – 18 years have been found to outperform average and late maturing boys for grip strength and shoulder pushing strength, reflecting the advanced skeletal age of the early matures, and hence the greater muscle mass (Malina et al., 2004d). Skeletal muscle is a major component of fat free mass (FFM). Skeletal muscle is the main work performing tissue of the body, and thus it is to be expected that there are positive associations between FFM and strength performance, in particular to static strength, as this is related to the cross-sectional area of the muscle. In physical tasks that require force to be exerted against an object, i.e. weight lifting, shot putting, or ball throwing a large FFM is important, but it can have a detrimental effect on tasks where the body must be moved such as in a vertical jump or when running (Malina et al., 2004d). FFM is significantly related to the strength of male adolescents. The correlation between strength and FFM is moderate once age, stature and body mass are controlled for in adolescent boys (Malina et al., 2004d). Girls have a less pronounced increase in static strength during their adolescent growth spurt than do boys, although it has been demonstrated that girls have an acceleration in arm-pull performance between the ages of 12 and 14.5 years (op.cit. Beunen and Thomis, 2000; Nash, 1987). Malina and Bouchard (2004b) found that in early adolescence, early maturing girls tended to be slightly stronger but the differences between the average, early and late matures reduced as adolescence continued. There is a paucity of data relating FFM to the strength of adolescent girls and young women (Malina et al., 2004d) and there are no studies examining the strength of elite and non-elite adolescent female athletes with respect to age and maturity.

The psychological characteristics of elite young athletes are vital to the understanding of what motivates the young athlete to perform and what motivates the young athlete to commit to the necessary intensive training that precludes high level success in sport. The drive to succeed, in spite of adversity and challenges, the persistence and constant effort that an athlete has to demonstrate in order to achieve their goals are some of the characteristics that may mark out the elite athlete from the non-elite athlete. Thus, much of relevant research in sport psychology has been based on achievement goal theory (Nicholls, 1984) which was developed in the mid-1980’s by researchers working mostly in education. Achievement behaviour is behaviour which is directed at developing and
demonstrating high ability rather than low ability. Levels of ability and task difficulty are judged as high or low when compared in relation to how an individual perceives their mastery, understanding and performance, therefore gains in mastery indicate competence (Nicholls, 1984). Task difficulty and ability are also defined as high or low relative to others in the same reference group as the individual. It is at this point that it becomes clear that a gain mastery does not necessarily indicate high ability. High ability is only demonstrated by achieving more, with less effort (or perceived effort) to others for an equal performance (Nicholls, 1984). Thus, task involved people feel a sense of achievement when they learn or improve whilst undertaking a task. Ego involved people gain their sense of competence by having superior performance or achieving the same result with less expenditure of effort (Harwood et al., 2008). How an individual defines success or failure, what their motivational processes and reactions are and any subsequent behaviours such as task choice, persistence and effort are all able to be defined within the structure of these two goal orientations (Harwood et al., 2008). Duda and Nicholls (1992) investigated Beliefs About the causes of Success in Sport and found that there was a belief that success in sport requires a high ability and the task orientation goal was associated with beliefs success requires effort, interest and collaboration with peers (Duda and Nicholls, 1992). Harwood et al. (2003, 2004) examined motivational profiles (based on achievement goal theory) and psychological skills usage in elite adolescent sports performers. The researchers felt that an athlete's motivational profile, i.e. are they high-task/high-ego, high-task/low ego, moderate-task/high-ego, moderate-task/moderate-ego, moderate-task/low-ego, low-task/high ego, low-task/moderate-ego or low-task/low-ego will affect the likelihood of the young elite athlete using psychological skills in practice and competition to enhance their success in their sport. There were sex differences in goal orientation with males being more likely to have a moderate to high ego orientation than the females. Athletes with higher task/moderate ego orientations were more likely to use psychological skills such as Imagery, Goal-Setting and Self-Talk (Harwood et al., 2003; Harwood et al., 2004).

There is a dearth of research examining the differences between the elite female adolescent athlete when compared to her non-elite age matched peers. Thus the purpose of the present study was to examine the physiological and psychological characteristics of the elite female adolescent athlete, to examine how these characteristics change over
time and to identify which characteristics might contribute to success in sport. The hypotheses to be tested are that the elite female athlete in comparison with non-elite controls will:

- Be a late maturer as defined by age of menarche and self-assessment of maturity
- Have a high peak oxygen uptake (l.min\(^{-1}\)) and (ml.kg\(^{-1}\).min\(^{-1}\))
- Have superior endurance fitness as reflected by a lower blood lactate concentration during submaximal treadmill running
- Have a higher power output during sprint cycling (W) and (W.kg\(^{-1}\))
- Have a psychological profile which prioritises practice and makes use of psychological skills
- Develop more over time in that the difference in performance and physiological variables will become greater with increases in chronological age or maturity in elite in comparison with non-elite participants
- And that the major factor that contributes to sporting success is a high peak oxygen uptake (l.min\(^{-1}\)) and (ml.kg\(^{-1}\).min\(^{-1}\)).
CHAPTER 2
The physiological and psychological characteristics of elite female adolescent athletes: a review of the literature

2.1 Introduction
This literature review will examine various aspects of the physiology and psychology of elite female adolescent athletes and their non-elite counterparts. Firstly, the physiology of the elite female adolescent athlete and her non-elite counterparts will be examined, with particular reference to growth, stage of maturation, chronological age and stage of menarche. The physiological responses to submaximal and maximal efforts during treadmill running will be examined, as will the physiological responses to a 30 second cycle ergometer test, and strength tests. Finally, the psychology of the elite female adolescent athlete will be examined with respect to achievement goal theory, beliefs about the causes of success and psychological skills.

For the purposes of this thesis it is necessary to define the participants being investigated and described. Throughout this thesis adolescence will be defined as the period of time that encompasses the period that includes sexual maturation until adulthood is reached (from 10 – 22 years in males and 8 – 18 years in females).

The female elite adolescent athletes in this study were deemed elite by virtue of attendance at a National Governing Body of Sport training camp or/and being a member of their sport’s national squad or/and competing in a national or international event.

The term ‘athlete’ in this review and throughout the thesis is used to refer to a sportsperson in serious training for any sport.

2.2 Growth and maturation

2.2.1 Assessment of maturation

Growth and maturation, although inextricably linked from birth, are not the same. Growth is defined as a ‘quantitative increase in size and mass’ (Bogin, 1988), and refers
to the increase in size as an individual grows heavier and taller and their proportions of lean and fat change. Girls experience a continuous rise in fat mass at the same time as an increase in muscle mass and skeletal mass, whilst boys gain primarily in muscle mass and skeletal mass (Baxter-Jones and Sherar, 2007). Changes in size occur as cells undergo one or more of three cellular processes; a) hyperplasia, or an increase in the number of cells; b) hypertrophy, or an increase in the size of the cell, and c) accretion, or an increase in the intracellular substances (Malina et al., 2004a). All three of these processes occur during growth, but which one is predominant at any one time is dependent on chronological age and the tissue involved. The number of neurons (brain cells) is established by mid-pregnancy, although hyperplasia of the nerve cells continues into the second half of gestation and on into the postnatal period. The number of muscle fibres is established by shortly after birth; both neural and muscle tissue grow primarily by hypertrophy (Malina et al., 2004a). Different parts of the body grow at differing rates and at different times in the lifecycle (Baxter-Jones and Sherar, 2007), ultimately however, all individuals eventually gain adulthood and full maturity, but all will end up as adults with different heights, physiques, and body composition (Malina et al., 1994).

Growth is the dominant biological activity during the first two decades of life (Claessens et al., 2000) in the healthy human being.

Maturation is more difficult to define. Biological maturation is defined as “a progression of changes that lead from an undifferentiated or immature state to a highly organised, specialised and mature state” (Bogin, 1988). Maturation has also been described as referring to the “tempo and timing of progress toward the mature state (i.e. menarche and the development of secondary sexual characteristics)” (Baxter-Jones and Helms, 1996). However, Cameron (2003) defines maturation as a process that is “continuous throughout life”. Maturation is not linked to chronological time, i.e. one year of maturational time is not the same as one year of chronological time (Cameron, 2003; Baxter-Jones and Sherar, 2007). This is often illustrated with the example of three (or more) individuals of exactly the same age who are all at widely differing stages of maturation, a fact that is clearly evidenced by the appearance of secondary sexual characteristics, differing proportions and distribution of body fat, and the development of the skeleton and musculature that define the sexually dimorphic body shapes of adulthood (Cameron, 2003). Franz Boas, early in the twentieth century described how
“some children are further along the road to maturity than others” (Tanner, 1962; Hauspie, 2002).

Maturation can be assessed by the identification of maturity indicators. These indicators divide the continuous process of maturation into discrete stages during skeletal and sexual maturation (Cameron, 2003). Skeletal age, sexual (secondary sexual characteristics) and age at peak height velocity (PHV) are the methods most commonly used to assess an individual’s progress through biological maturation (Malina, 1994a). Biological maturity can be defined by the chronological age at peak height velocity (Baxter-Jones and Sherar, 2007). Sexual maturity is defined as fully functional reproductive capability (Malina et al., 2004a). Skeletal maturity is the fully ossified skeleton of an adult (Malina et al., 2004a). Chronological age on its own has limited use as an indicator of biological maturity (Claessens et al., 2000).

Skeletal age is thought to be the most accurate method of assessing biological maturation (Malina et al., 2004a), but requires the hand and wrist of the individual to be x-rayed in order to assess the structure and shape of the bone. This method is not used widely as there are ethical and cost considerations to be taken into account by the researcher, even though the amount of radiation that an individual would be exposed to per screening would be less than the background radiation that they would be exposed to during an aeroplane flight to Europe at the current time (personal communication, Johnson, 2008).

When an individual has reached peak height velocity their biological maturity age is said to be 0.0 years (Baxter-Jones and Sherar, 2007). Individuals can be identified as early, average or late maturers according to when they achieve peak height velocity. Early maturers are those who reach peak height velocity more than one year earlier than the mean age and late maturers would be those who attain peak height velocity more than one year later than the mean age (Baxter-Jones and Sherar, 2007). Peak height velocity is difficult to pinpoint and can only be accurately determined by frequent and regular longitudinal measurements commencing in pre-puberty. Girls usually reach peak height velocity at around 12 years of age (Baxter-Jones and Sherar, 2007) though the age range is from 9.2 years to 15.0 years (Malina et al., 2004a). Boys, in contrast
reach peak height velocity at around 14 years of age (Baxter-Jones and Sherar, 2007) with an age range of 12.0 years to 15.8 years (Malina et al., 2004a).

2.2.2 Assessment of sexual maturation
Sexual maturation refers to the changes in secondary sex characteristics that occur throughout the pubertal period, leading to full sexual maturity (Claessens et al., 2000). Sexual maturity is often assessed by examination of the secondary sex characteristics; the assessment is usually made using Tanner’s (1962) indices for sexual maturation. Tanner’s indices for sexual maturation are a five stage scale for pubic hair and genital development in boys and pubic hair and breast development in girls which are based on the work of Reynolds & Wines (1948 & 1951 op cit (Claessens et al., 2000). The assessment is ideally made by visual examination of the nude body by a trained professional. However, this method is very invasive and adolescence is a very sensitive time; in order to address these issues self-assessment by the individual has been proposed and is regularly used as an alternative method of assessment of maturation status. Self-assessment proved to be a reliable and valid method for obtaining this data (Duke et al., 1980; Claessens et al., 2000; Leone and Comtois, 2007; Morris and Udry, 1980). Leone and Comtois (2007) found that Spearman’s correlation between the physician’s ratings for pubic hair development and the adolescents’ self-assessments ranged from 0.97 and 0.86 for males and females respectively. The agreement between physician and female adolescent athletes for breast development was excellent (Spearman 0.9) (Leone and Comtois, 2007). Morris and Udry (1980) also found a good concordance between the physician’s observations and female adolescents’ self-assessments for breast development (Pearson Correlation Coefficients – 0.63, P<0.05) and pubic hair development (0.81, P<0.05). Male adolescents’ self-assessments of pubic hair development had good agreement with the physician observations (0.63, P<0.05) (Morris and Udry, 1980). However, Cameron (2003), states that it is essential that the procedure for self-assessment is carefully and thoroughly explained to the participant in non-scientific language in order to maximise the validity of the procedure.

2.2.3 Maturational status of elite and non-elite adolescent females
The effects of training on the sexual maturation of adolescent girls has been the subject of regular investigation, particularly with reference to the possible effects on the onset of menarche and the long term reproductive health of the athlete. The age of menarche
in athletic populations has been observed to be later than that for non-athletic populations (Malina et al., 1978; Malina, 1983; Stager et al., 1984). The reasons for this are unclear, with some researchers suggesting that intense physical activity or training prior to menarche may be the underlying reason for the delay in reproductive development (Frisch et al., 1981).

Claessens et al., (1992) investigated 201 elite artistic gymnasts who were competing at the 24th World Championship Artistic Gymnastics in Rotterdam in 1987. As the gymnasts were predominantly of European ancestry (59%) a comparison group of non-athletic Flemish girls from the Leuven Growth Study were used as controls. The age range of the gymnasts was 13.2 - 23.8 y with a mean of 16.5 ± 1.8 y. The elite gymnasts were considerably shorter and lighter with narrower shoulders and hips than the reference medians but proportional differences in contrast to absolute body size, between the gymnasts and the non-athletes were minor (Claessens et al., 1992). The elite gymnasts attained menarche much later than the non-athletes which is consistent with other studies (Malina, 1983). This difference in mean age at menarche was probably due to genetic factors as Peltenburg et al (1984) reported that the parents of nationally selected Dutch gymnasts had smaller mid-parent stature than average which implies a genetic predisposition towards shorter stature.

A cross-sectional study of young (aged 9-13 y) male and female Danish swimmers, tennis players, team handball players, and gymnasts who were all competing at regional or national level was undertaken to investigate the body composition, anthropometric variables and pubertal development of young athletes, and also to explore the influence of age, sport, training hours, and pubertal development/menarcheal age on body composition and pubertal development (Damsgaard et al., 2001). In the girls, age and maternal menarcheal age were significantly associated with breast development. Early menarche in the mothers was associated with an earlier puberty in their daughters'; this was most evident in the swimmers, with the gymnasts being the least developed in their puberty. There were differences in anthropometric data and body composition between the athletes of both sexes in swimming, tennis, team handball and gymnastics and these were more evident in the girls. No association of training with height, body composition and pubertal development was found, suggesting that training had no effect
on those parameters and that perhaps the children involved in these particular competitive sports were selected on the basis of genetic factors (Damsgaard et al., 2001).

Geithner et al (1998) investigated longitudinally, Polish girls active and not active in sport. The active girls were rowers, swimmers or track athletes and were training for around 12 hours per week during puberty (around $3.9 \pm 1.2$ yr) although they were not classed as elite. There were no significant differences between the two groups of girls for age at peak height velocity and age at menarche, though the girls active in sport were slightly later in attaining both peak height velocity and menarche than the non-active girls. The interval between peak height velocity and menarche, peak height velocity (cm.y$^{-1}$), ages at attaining pubic hair and breast stages 3, 4 and 5 and the intervals between the stages did not differ significantly between the girls who were actively training and those who were not (Geithner et al., 1998). The study concluded that regular training in sport during puberty and the adolescent spurt does not appear to influence the timing and progression of maturation, somatic or sexual, in girls (Geithner et al., 1998).

Young male and female athletes in most sports are, on average, taller and have body masses that equal or exceed the reference medians (Malina, 1994a; Baxter-Jones and Maffulli, 2002), the exceptions to this being gymnasts, ballet dancers, figure skaters of both sexes and weight lifters and male divers (Malina, 1994a; Baxter-Jones and Maffulli, 2002), who all tend to have shorter statures. The ballet dancers tend to catch up with non-dancers in late adolescence (Baxter-Jones and Maffulli, 2002). Female gymnasts, figure skaters and ballet dancers consistently have lighter body mass than the reference medians, though the gymnasts and figure skaters have an appropriate body mass for their height, which is not the case for ballet dancers and distance runners (Baxter-Jones and Maffulli, 2002). Although young female athletes tend to be heavier than the normal population they also tend to have a lower percentage of body fat (Baxter-Jones and Maffulli, 2002).
2.2.4 Recording the onset of menarche and maternal menarche

In girls, age at menarche is the most reliable indicator of maturity and is the maturational landmark most often studied in elite athletes (Beunen and Malina, 2008). The timing of menarche is closely related to the indicators of skeletal, sexual and somatic maturation, with considerable variation amongst individuals (Malina et al., 1979) and generally occurs at around 1 year after peak height velocity (Geithner et al., 1998; Malina et al., 2004e). The information about the date of menarche is usually obtained by one of three methods; by recall through questionnaire or interview; by prospective study where the individual is interviewed or questioned regularly from pre-puberty onwards; or lastly; in cross-sectional studies by the status quo method which yields an estimate of the median age at menarche based on chronological age for the entire cohort being investigated (Malina, 1994a). Menarche is defined as the first menstrual flow (Malina, 1983). Recall data is influenced by error in recall, though various studies over the years have reported validity of recall with reasonable accuracy (Koo and Rohan, 1997).

In 1976, 63% of 339 Swedish girls whose age at menarche had been recorded by school nurses, could recall menarche to within ± 3 months of the actual date when surveyed, during a longitudinal study, four years later (Bergsten-Brucefors, 1976) with 91% of the girls accurate to within one year. Bean et al (1979) also examined the accuracy of recall using questionnaires, in a cohort of 160 women who had recorded their menstrual and reproductive events as they occurred. 90% of the women reported age at menarche to within one year and 59% reported age at menarche accurately even though there was between 17 years and 53 years (with a mean of 33.9 years) since the actual occurrence of the event (Bean et al., 1979). Actual age at menarche was recalled to within one year of the event by 84% (P<0.01) of 50 middle-aged participants (mean age 50 years) in a longitudinal study from childhood, in which the participants were investigated during childhood (aged 5 – 7 years), adolescence (aged 10 – 18 years), and at ages 30 and 40 (Casey et al., 1991). These results and others, suggest that most teenagers and adult women can recall this maturational landmark with sufficient accuracy for group comparisons. Factors that are known to affect the age of menarche are family size and birth order of the participant and her siblings (Malina et al., 1979).
Malina et al (1979) investigated the age at menarche, family size and birth order of 145 athletes at the Montreal Olympic Games in 1976. Most of the athletes were from Canada, Great Britain or the United States, (76% were from these three countries) although there were athletes from 27 countries in total. It was reported that athletes were more likely to attain menarche later than the general population for their countries, with the mean age of menarche among this sample being $13.66 \pm 0.12$ years, with 6 of the athletes not yet having had their first menstrual period. Athletes from larger families, particularly rowers and track and field athletes, were found to be more likely to have a later menarche than those from smaller families, with the exception of the swimmers studied, who attained menarche at around the same age as the general population (Malina et al., 1979).

In a later study Malina et al. (1997a) investigated a much larger cohort of 370 university athletes, who participated in seven sports, and collected data, by retrospective questionnaire, on age at menarche, number of children in the family (family size) and birth order. The status of the athlete was not defined. Of the cohort, 79% were white and 21% were black. The investigation was conducted between 1984 and 1994, and from 1990 onwards retrospective age of menarche of the athlete’s mothers was also obtained as an indicator of the familial or genotype contribution to this indicator of maturation in athletes (Malina et al., 1994). It was found that, after controlling for birth order, menarche was later by around $2.0 - 2.6$ months for each additional sibling in the family and even after controlling for age at menarche of each athlete’s mother the effect remained (Malina et al., 1997a). The age that a girl attained menarche was closely related to age that her mother attained menarche, suggesting a strong familial or genotype link.

Malina et al (1994) obtained retrospective ages at menarche from a group of 109 university athletes and their mothers, and also from 77 sisters of the athletes. These athletes had a mean age of menarche of $13.8 \pm 1.5$ years. The mean age of menarche of the mothers was $13.4 \pm 1.7$ years. When the mothers were subdivided into athletes ($n=52$) or non-athletes ($n=57$) the mean ages for menarche were $13.7 \pm 1.8$ years for the mothers who were athletes and $13.2 \pm 1.2$ years for the mothers who were non-athletes, which was not significant. The athletes who had sisters ($n=62$) and the sisters ($n=77$)
had mean age of menarche of 14.0 ±1.4 years and 13.6 ± 1.6 years respectively. These sister – sister interclass correlations for athletes (0.44 and 0.39) are slightly higher than those for non-athletes (0.25-0.30). There was a significantly higher correlation between the mothers who were athletes and their athlete daughters than there was between the mothers who were not athletes and their athlete daughters. The results of this study suggest that the later menarche often seen in athletes is probably familial. Malina goes on to point out that at the time of this study the opportunities for organised sport for women of the mother’s generation at college or university level in the United States was very limited and this strengthens the case against training being implicated in late onset of menarche or delayed maturation (Malina et al., 1994).

More recently the somatic growth, sexual maturation and final adult height of elite adolescent female athletes was investigated (Erlandson et al., 2008). This study revisited the data from the Training Of Young Athletes study (1987-1992) (Baxter-Jones et al., 1994; Baxter-Jones et al., 1995), a large longitudinal study of elite age-grouped UK male and female athletes in four sports; tennis, football, swimming, and gymnastics. In 2000 all the original participants (n=453) were contacted by mail and asked to respond to a questionnaire. Over 200, 45.5% questionnaires were returned, of which 110 were from female respondents; 47% gymnasts (n=38), 49% tennis players (n=38) and 60% swimmers (n=34). Follow-up measurements were obtained through a self-report questionnaire in autumn 2000, 10 years after the conclusion of the initial study. The participants were provided with detailed instructions on how to accurately measure their current height and were asked to report this. They were also asked to recall age at menarche and to provide information on current sports involvement and date of retirement from sport if applicable (Erlandson et al., 2008). In this follow-up study no significant differences were found between predicted adult heights and attained adult heights, nor were sports group differences found. The gymnasts attained menarche at a significantly older age than the tennis players. There were no significant differences in adult height in any of the three athlete groups, or between those who had retired in adolescence and those who had continued to participate in any of the sports. The average ages of entry into breast and pubic hair stages 5 by the gymnasts were significantly older than those of the tennis players and the swimmers, even though there had been no differences at earlier stages of maturation. This suggests that at the later
stages of maturation, the rate of development, or tempo, is slower in the gymnasts than in the tennis players or swimmers. This could be due to either, an effect of training, or to late maturing athletes persisting in the sport and the earlier maturing athletes dropping out of the sport, which would result in an older average age for reaching this stage of sexual maturation (Erlandson et al., 2008). The study concluded that it appeared that regular training did not affect final adult stature and that, when aligned with biological age, the tempo of sexual maturation was similar in these young athletes (Erlandson et al., 2008).

Tanner (1962, pp 113 - 115) noted that the timing of menarche was, to a considerable extent, under hereditary control with the probability that the inheritance of an early menarche is as likely to come from the father as from the mother (Tanner, 1962). Tanner also says “the one thing that all authors find significantly related to age at menarche is the number of children in the family. The larger the number the later the menarche....” (Tanner, 1986).

Thus the present findings in the literature suggest that while late maturation seems to be advantageous for female gymnasts, for other sports the role of maturation in sport selection and progression remains unclear.

2.3 Interpretation of body-size related exercise performance during growth – cross sectional data

2.3.1 Introduction
As a child grows and matures they experience dramatic changes in body size. These changes need to be accounted for when interpreting data in order that appropriate comparisons can be made. Two adolescents of the same chronological age may be at widely differing stages of biological and sexual maturation. The increases in body size and the markers for exercise performance have consistently shown strong Pearson product-moment correlation coefficients between them of ~ r=0.7 – 0.8 (Welsman and Armstrong, 2007). Therefore it is important that some method of normalising the data is used so that, where appropriate, like is compared with like. However it is not always
appropriate to scale for body size when considering sporting performance as size itself may be a key factor in performance.

2.3.2 Ratio scaling

Ratio scaling has been the traditional method for ‘normalising’ physiological data for many years. Inter-individual differences are controlled for by dividing the absolute measure by body mass. This gives a ‘per body mass’ ratio, such as ml.kg⁻¹.min⁻¹ for oxygen uptake, W.kg⁻¹ for mechanical power, and Nm.kg⁻¹ for maximal torque. This method assumes that differences in the physiological variable that are due to the size of the subject will have been removed, thus making the scaled physiological performance variables independent of the subject’s body size dimension (Nevill et al., 1992). This method was called the ‘ratio standard’ by Tanner (1949). Tanner (1949) recognised that there are theoretical and statistical limitations to simple ratio scaling, and warned against the use of these standards when making comparisons of groups based on mean values of ratio standards, arguing that these were misleading because the ratio standard implies that the line of regression (the line that most closely fits the actual data) passes through the point of origin when this is not the case. Indeed, Tanner stated “such standards are theoretically fallacious, and in practice (except in very special circumstances…) misleading” (Tanner, 1949 pp 1). The effect of this distortion is to advantage small individuals and disadvantage large people (Tanner, 1949; Winter, 1992). Tanner (1949) recommended that data pertaining to an individual should be assessed by comparison against regression standards, whilst intergroup data comparisons should be based on analysis of covariance (ANCOVA) which calculates adjusted means (Winter, 1992). However, Nevill et al (2004) investigated whether or not the ratio standard was an appropriate method of normalising $\dot{V}O_2$ max to predict the speed of a 1-mile run in a group (n=36) of 12 year old boys. A power function model and log-linear regression were used to find the best predictor of 1-mile run speed; this was given by speed (m s⁻¹)=$55.1 \dot{V}O_2$ max⁰.⁹₈₆m⁻⁰.⁹₆. As both the $\dot{V}O_2$ max and the body mass exponents were close to unity, albeit with opposite signs, the model suggests that the best predictor of 1-mile run speed is almost exactly the same as the traditional ratio scaling standard as recorded using the units (ml.kg⁻¹.min⁻¹). An earlier study by Nevill et al (1992) found that the traditional ratio standards (ml.kg⁻¹.min⁻¹) and (W.kg⁻¹) were
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found to best describe a wide range of subjects according to their performance capacities or ability to run – which are highly dependent on body size. The same wide range of subjects' ability to utilise oxygen or to record power maximally were best described by the use of power function ratio standards (ml.kg$^{-2/3}$.min$^{-1}$) and (W.kg$^{-2/3}$), arrived at by use of a curvilinear power function model which Nevill et al (1992) found to be superior in all respects to linear models.

2.3.3 Interpretation of body-size related exercise performance during growth – longitudinal study

Multilevel modelling has been designed for longitudinal studies, particularly those that investigate the effects of maturation, development, and growth on performance. These studies use a repeated measures design. Multilevel modelling can be used to fit growth curves to performance data, and is particularly useful as it can be used with either discrete or continuous responses, and is able to account for base lines that are not steady (Winter, 1992).

2.4 Development of peak oxygen uptake

2.4.1 Maximal oxygen uptake and peak oxygen uptake

Maximum oxygen uptake or $\dot{\text{V}}\text{O}_2\text{ max}$, is the maximum amount of oxygen that the body can consume during work for the aerobic production of ATP (Wilmore and Costill, 1999; Armstrong and Welsman, 2000b; ACSM, 2000). In children and adolescents maximum oxygen uptake ($\dot{\text{V}}\text{O}_2\text{ max}$) is usually replaced with the peak oxygen uptake ($\dot{\text{V}}\text{O}_2\text{ peak}$) measurement as it is rare that children and adolescents reach the plateau in oxygen consumption that is normally seen in adults (Armstrong and Fawkner, 2007). Peak oxygen uptake is defined as "the highest oxygen uptake observed during an exercise test to exhaustion" (Armstrong, 2007). The capacity to perform aerobic exercise is limited by the $\dot{\text{V}}\text{O}_2\text{ max}$ of the exercising individual (ACSM, 2000 p.66). $\dot{\text{V}}\text{O}_2\text{ max}$ is widely recognised as the best measure of aerobic fitness, and is the product of maximal cardiac output (L blood.min$^{-1}$) and the arterial-venous oxygen difference (mL O$_2$ per L blood) (ACSM, 2000 p.66).
Laboratory testing for VO₂ max assumes that as the intensity of exercise gets higher the oxygen uptake will increase until it reaches a critical point beyond which no further increase in oxygen uptake can take place and a plateau occurs before exercise capacity is reached (Rowland, 1989). The majority of children and adolescents have been found to be unable to exercise to exhaustion and reach a plateau in the same way that adults do (Åstrand, 1952; Rowland, 1989; Rivera-Brown et al., 1992). Why some individual young people demonstrate a plateau in oxygen uptake and others do not has yet to be fully ascertained. However, it is noticeable that it is impossible to distinguish those individuals that demonstrate a plateau from those that do not (Armstrong and Welsman, 1994; Armstrong et al., 1996).

2.2.4 Peak oxygen uptake and age

Peak VO₂ (scaled using a variety of methods) in children and adolescents has been extensively studied over the past 50 years. Armstrong and Welsman (1994, 2000a) carried out thorough reviews of the extant literature and, after great care was taken in the selection of the published studies to exclude trained children in studies that included both trained and untrained subjects and to avoid using studies that involve dual publication of the same data base in a different format, they collated the data from over 4937 treadmill determined peak VO₂ data points from subjects aged 8 - 16 years. When the data was plotted there was an almost linear increase in VO₂ peak (l.min⁻¹) with age in both sexes. Regression equations showed that between the ages of 8 and 16 years in males and females, VO₂ peak increases 1.42 - 3.68 (l.min⁻¹) and 1.27 - 2.65 (l.min⁻¹) respectively (Armstrong and Welsman, 2000a). Whilst there have been very few longitudinal studies with a substantial ‘n’ of > 20 male or female subjects, that have investigated young people’s VO₂ peak, nonetheless it is interesting to note that the data from those studies that are in the literature is in general agreement with the data from cross-sectional studies (Armstrong and Welsman, 2000a). Mirwald and Bailey (1986) followed a cohort of Canadian boys (n=75) aged 8 - 16 years and a similar cohort of Canadian girls (n=22) aged 8 - 13 years annually, for 10 years for the boys and 7 years for the girls. The data from the boys shows a steady increase in VO₂ peak (l.min⁻¹) from 8 - 16 years, in total by 164% with an average increase of 11% per annum (Mirwald and Bailey, 1986). The VO₂ peak (l.min⁻¹) of the girls in the Canadian
study increased by 73% from 8 – 13 years with annual increases of around 12% (Mirwald and Bailey, 1986). In other longitudinal studies (Šprynarová et al., 1987; Armstrong and Van Mechelen, 1998; Armstrong et al., 1999; Armstrong and Welsman, 2001) from Czechoslovakia, Holland, and the U. K., the boys’ data for \( \dot{V}O_2 \) peak (L.min\(^{-1}\)) showed similar findings to the Canadian study with \( \dot{V}O_2 \) peak (L.min\(^{-1}\)) values increasing steadily, with the largest annual increases occurring between 13 and 15 years of age. The girls’ data was less consistent and \( \dot{V}O_2 \) peak (L.min\(^{-1}\)) appears to rise progressively until about 13 years and then start to level off from around 14 years old. The British girls showed an increase of 12% from 13 to 17 years, whilst the Dutch girls’ \( \dot{V}O_2 \) peak (L.min\(^{-1}\)) only showed an increase of 2% between the ages of 14 to 16 years of age. Increases in \( \dot{V}O_2 \) peak with age are thought to reflect the increasing dimensions of the oxygen delivery chain as well as the increase in size of the exercising muscle mass in children and adolescents as they progress through puberty to maturity (Rowland, 2005; Armstrong and Fawkner, 2007).

### 2.4.3 Peak oxygen uptake and body mass

\( \dot{V}O_2 \) peak and body size are strongly related, with correlation coefficients describing its relationship with body mass or stature typically exceeding \( r = 0.70 \) (Armstrong and Welsman, 2000a). Therefore, most of the age-related increase in \( \dot{V}O_2 \) peak can be said to reflect the overall increase in body-size during the period of growth and maturation as an individual progresses through childhood, into adolescence and beyond to adulthood. Because most physical activity involves moving the body-mass from ‘a’ to ‘b’ it has become the norm to express \( \dot{V}O_2 \) peak in ratio with body-mass as millilitres of oxygen per kilogram of body mass per minute (mL.kg\(^{-1}\).min\(^{-1}\)) which allows changes in body mass due to age-related growth to be accounted for. The data produced by this method are consistent and show that over the age range 8 to 18 years boys’ mass related \( \dot{V}O_2 \) peak (mL.kg\(^{-1}\).min\(^{-1}\)) remains relatively static at around 48 to 50 mL.kg\(^{-1}\).min\(^{-1}\), whilst girls’ \( \dot{V}O_2 \) peak (mL.kg\(^{-1}\).min\(^{-1}\)) mass related data shows that their \( \dot{V}O_2 \) peak (mL.kg\(^{-1}\).min\(^{-1}\)) declines progressively from around 45 to 35 mL.kg\(^{-1}\).min\(^{-1}\) (Krahenbuhl et al., 1985; Armstrong and Welsman, 1994).
However, whilst acknowledging that expression of $\dot{V}O_2$ peak in ratio with body-mass has been the conventional way to control for body mass during growth, it is becoming increasingly common for researchers to use other scaling methods. Welsman et al. (1996) used both ratio scaling (mL.kg$^{-1}$.min$^{-1}$) and log-linear analysis of covariance (allometric scaling) to remove the effects of body-size from $\dot{V}O_2$ peak in groups of prepubertal boys and girls, circumpubertal boys and girls, and adult men and women. In males the ratio (mL.kg$^{-1}$.min$^{-1}$) analyses were consistent with the extant literature and showed no significant differences between the three groups, prepubertal 50±4 ratio mL.kg$^{-1}$.min$^{-1}$, circumpubertal 53±4 ratio mL.kg$^{-1}$.min$^{-1}$, and adults 53±3 ratio mL.kg$^{-1}$.min$^{-1}$ in mass-related $\dot{V}O_2$ peak. Log-linear analysis of covariance, on the other hand, revealed significant progressive increases in $\dot{V}O_2$ peak across all three groups, with 2.25 l.min$^{-1}$, 2.50 l.min$^{-1}$, and 2.80 l.min$^{-1}$ respectively, indicating that relative to body-size $\dot{V}O_2$ peak increases during growth rather than remaining static. Likewise, the girls' mass related $\dot{V}O_2$ peak (mL.kg$^{-1}$.min$^{-1}$) was consistent across the prepubertal and circumpubertal groups with 45±3(mL.kg$^{-1}$.min$^{-1}$) and 47±4 (mL.kg$^{-1}$.min$^{-1}$) respectively and demonstrated a significant decrease between the circumpubertal and adult 43±3(mL.kg$^{-1}$.min$^{-1}$) groups. When log-linear analysis of covariance was applied to the same data set a very different picture emerged, 1.99(l.min$^{-1}$), 2.19(l.min$^{-1}$) and 2.13(l.min$^{-1}$), respectively with $\dot{V}O_2$ peak significantly increasing into puberty and with no decline in adulthood apparent (Welsman et al., 1996).

Longitudinal analysis of data is complex but recent developments in statistical analysis has seen the emergence of multi-level modelling techniques which allow the researcher to partition body-size, age and sex effects at the same time in order to give a greater understanding of the longitudinal data set.

2.4.4 Peak oxygen uptake and maturity
When considering the physiological responses of adolescents it is important that their biological age as well as chronological age is taken into consideration. The development of $\dot{V}O_2$ peak is likely to be influenced by an interaction between body-size and maturational effects. There are relatively few studies that have investigated the
relationship between maturation and $\dot{\text{VO}}_2$ peak possibly because of the difficulties of assessing maturation as mentioned earlier. Using ontogenic (computation of a body size exponent for each subject) allometry, Beunen et al (1997) investigated $\dot{\text{VO}}_2$ peak using cycle ergometry in a group of Polish girls and boys grouped by maturity status, all of whom were enrolled in mid-level (not elite) sports schools. The boys trained in track, wrestling and basketball, whilst the girls trained in track and rowing. The young athletes trained between 8 and 12 hours per week but were not classed as elite. Of the cohort, 47 boys and 31 girls had complete longitudinal records from 11 – 14 years of age and these were used to analyse oxygen uptake over time (Beunen et al., 1997). Ontogenic allometry was used to analyse the differential growth in the individual growth processes. Double logarithmic transformations of $\dot{\text{VO}}_2$ peak and body mass, and $\dot{\text{VO}}_2$ peak and stature were carried out for each subject. The results of the analysis indicated that in early and average maturing boys $\dot{\text{VO}}_2$ peak increased at a slightly higher rate than that expected from the increase in body mass, but in late maturing boys the increase was lower than expected. In the girls the analysis showed that changes in $\dot{\text{VO}}_2$ peak were not related to growth in either body mass or stature possibly because a number of girls showed no clear increase in $\dot{\text{VO}}_2$ peak even though all the girls showed an increase in stature and body mass over the 3 years of observation (Beunen et al., 1997).

Geithner et al (2004), undertook a study of 48 males and 35 females followed longitudinally from 10 to 18 years of age to investigate the growth in peak aerobic power during adolescence and to identify the age at peak velocity (PV) for $\dot{\text{VO}}_2$ peak (PVP $\dot{\text{VO}}_2$). Peak aerobic power was measured annually during a maximal treadmill test, whilst height and weight were measured semi-annually to enable an estimate of age at peak height velocity (PHV) and age at peak weight velocity (PWV). Age at PVP $\dot{\text{VO}}_2$ (l.min$^{-1}$) was compared with ages at PHV and PWV. The analysis showed that the growth spurt occurred earlier in females (12.3±1.2 yrs) than in males (14.1±1.2 yrs), and that $\dot{\text{VO}}_2$ peak (l.min$^{-1}$) increases in both sexes throughout adolescence, with males having higher values than females at all ages (Geithner et al., 2004).
2.4.5 Peak oxygen uptake and performance

Whilst it is becoming clear that using traditional ratio scaling is problematic with analysis of longitudinal data where the effect of body mass needs to be accounted for, it has been noted in recent research by Nevill et al. (2004) that the ratio standard may be a more appropriate denominator than allometric scaling, when related to field performance such as prediction of performance in distance running. Using a power function model and log-linear regression, these researchers found that the best predictor of 1-mile run speed was given by: speed (m s$^{-1}$) = $55.1 \bar{VO}_2 \text{max}^{0.986} m^{-0.96}$. With both the $\bar{VO}_2 \text{max}$ and the body mass exponents being close to unity but with opposite signs, the model suggests that the best predictor of 1-mile run speed is almost exactly the traditional ratio standard recorded in the units (mL.kg$^{-1}$.min$^{-1}$). They conclude that $\bar{VO}_2 \text{max}$ recorded in the traditional units (mL.kg$^{-1}$.min$^{-1}$) still has a valuable place in publishing the results of studies of cardiovascular fitness of both children and adults (Nevill et al., 2004).

Consistent with the view that $\bar{VO}_2 \text{max}$ (mL.kg$^{-1}$.min$^{-1}$) is a valuable variable relating to performance it was shown in a group of highly conditioned females (18 – 33 y) that there was a strong relationship between $\bar{VO}_2 \text{max}$ (mL.kg$^{-1}$.min$^{-1}$) and 5 k (r=0.9), 10 km (r=0.92) and 16 km (r = 0.88) pace (Fay et al., 1989).

More recently, a study investigating the physiological correlates with endurance running performance was undertaken with trained adolescents of both sexes (Almarwaey et al., 2003). The study examined the relationship between competitive 800-m and 1500-m performance times in a group of endurance trained adolescent male (n=23) and female (n=17) runners. The relationships between the performance times and the following variables were examined; $\bar{VO}_2 \text{peak}$, running economy, and estimated running speed at $\bar{VO}_2 \text{peak}$ ($v\bar{VO}_2 \text{peak}$), and running speed at blood lactate concentrations of 2.0, 2.5 and 4.0 mmol.L$^{-1}$ (Almarwaey et al., 2003). Running economy and $v\bar{VO}_2 \text{peak}$ were significant variables for the boys’ 800 m ($r=0.62$ and -0.62, $P<0.01$). Once the girls’ chronological age had been partialled out, none of the measured variables were significantly related to 800 m performance. For the 1500 m event $\bar{VO}_2 \text{peak}$, $v\bar{VO}_2 \text{peak}$, and the running speed at 2.5 mmol.L$^{-1}$ were significant independent variables for boys ($r= -0.43, -0.39$ and - 0.53, $P<0.05$) and girls ($r= -0.50, -0.61$, and $-0.54$, }
P<0.05). In addition the $\bar{VO}_2$ at 2.5 mmol.l$^{-1}$ was related to the 1500 m time in the girls ($r=-0.54$ P<0.05). This study concluded that the physiological variables that were most strongly correlated with middle distance running performance in either sex were blood lactate concentration at 2.5 mmol.l$^{-1}$ and the v$\bar{VO}_2$ peak. To a lesser extent $\bar{VO}_2$ peak may also have a role though this is likely to be accounted for by v$\bar{VO}_2$ peak (estimated running speed at $\bar{VO}_2$ peak) (Almarwaey et al., 2003).

Mayers and Gutin (1979) observed that percentage $\bar{VO}_2$ peak at running speeds of 5, 6 and 7 mph was highly correlated ($r=0.8$) with 1 mile run performance in both elite male runners and non-runners age 8 – 11 years of age. However, within the running group only $\bar{VO}_2$ peak at 8 mph was significantly associated with 1 mile run performance ($r=0.87$) (Mayers and Gutin, 1979). Unnithan et al (1995) found that percentage $\bar{VO}_2$ peak at 11.2 and 12.8 km.h$^{-1}$ ($r=0.61$ and 0.67; respectively) was significantly related to 3 km run performance in trained pre-pubertal runners (Unnithan et al., 1995).

2.4.6 Peak oxygen uptake in elite and non-elite adolescents
Comparing elite with non-elite adolescent athletes is problematic as there are few studies that have investigated these two populations together. Such a study is that of Van Huss et al (1988) who investigated young male (n=20) and female (n=22) elite runners aged 9 – 15 years and compared them with young male (n=15) and female (n=11) untrained control subjects. The elite runners of both sexes had a consistently higher maximum oxygen uptake and worked for longer and attained higher $\bar{VO}_2$ max values than the control groups P<0.01 (Van Huss et al., 1988).

In summary, findings from studies examining the elite adolescent suggest the peak $\bar{VO}_2$ is higher in this group than in the non-athletic population. There have been few studies on females and none making comparison with age and maturity matched controls.
2.5 Development of running economy

2.5.1 Introduction
Economy of energy expenditure is important in any endurance event which makes demands on aerobic energy supply (Cooke, 2001). The energy expenditure associated with movement is that of economy of locomotion. Running economy is the oxygen demand ($\dot{V}O_2_{\text{submax}}$) of running at a specified velocity (Pate et al., 1992). In order to produce the optimum performance in any endurance running event it is essential that there is efficient utilisation of available energy (Daniels, 1985). Thus, running economy is the relationship between running velocity and energy expenditure (Daniels, 1985). If locomotion economy can be optimised, the capability to perform locomotor activities without unnecessary fatigue is enhanced, leading, ultimately, to improved endurance performance in children and adults (Morgan, 2000).

2.5.2 Running economy, body mass and age
Åstrand (1952) conducted some of the earliest work on running economy in children. Åstrand found that steady-state submaximal $\dot{V}O_2$ (ml.kg$^{-1}$.min$^{-1}$) at any given running speed fell with increasing age; in males and females aged between 4 and 15 years, the decrease was 47.0 – 39.0 and 45 – 37 ml.kg$^{-1}$.min$^{-1}$ respectively. This suggested that as the children were getting older they had a reduced demand for oxygen and were thus becoming more economical (Åstrand, 1952 p.129). Åstrand declares that

"all subjects have been rather well trained due to regular participation in gymnastics and games....the older subjects were students from Gymnastika Centralinstitutet, Stockholm......and are a selected group which are better equipped to physical working capacity than men and women usually are"

(Åstrand, 1952 p.11).

It is unclear whether the improvement in running economy was due to training (if indeed, any specific running training took place), or whether it was a function of growth. Age is only quantified chronologically in this early study. A later longitudinal study by Daniels et al. (1978) followed male children engaged in running training from around 10 years of age to late adolescence/early adulthood (18 years old). During the 8 year period studied, the $\dot{V}O_2$ max (l.min$^{-1}$) and body mass of the subjects increased steadily as they grew older. When $\dot{V}O_2$ max was expressed in ml.kg$^{-1}$.min$^{-1}$ to correct
for the gain in body mass, VO$_2$ max remained unchanged over the 8 year period even though running performances in the 1 and 2 mile runs improved steadily reflecting an improved running economy (Daniels et al., 1978; Krahenbuhl and Williams, 1992). Again, this study fails to make clear whether the training was the cause of the improvement in running economy or whether it was a function of growth and gain in body mass.

Krahenbuhl et al (1989) conducted a longitudinal study in which the male subjects, all typically active teenagers but not engaged in running training, were tested at 10 years of age and again at 17 years old. During the 7 years between measurements, the subjects gained in height, weight and leg length, and experienced a small reduction in the sum of two skinfolds. The 'n' was small for this study (n=6) but the results were still clear. The subjects were tested at mean ages of 9.9 (T1) and 16.8 years (T2). Over the 7 year period relative VO$_2$ max (ml.kg$^{-1}$.min$^{-1}$) remained unchanged (T1, 48.9 (ml.kg$^{-1}$.min$^{-1}$); T2, 47.8 (ml.kg$^{-1}$.min$^{-1}$)) and running economy improved (T1, 234.2 (ml.kg$^{-1}$.km$^{-1}$); T2, 202.8 (ml.kg$^{-1}$, km$^{-1}$)), 9 minute run distance increased (T1, 1637 m; T2, 2115 m), and the estimated percent of VO$_2$ max incurred during the 9 minute run increased from 85.5% (T1) to 99.5% (T2). This study concluded that improvement in distance running performance in adolescent boys was not dependent on training status and that improvements in running economy accompany growth. Another longitudinal study, this time with both males and females, aged between 13 to 27 years, and with a far more substantial 'n' (84 males and 98 females) was undertaken as part of the Amsterdam Growth and Health study (Ariëns et al., 1997). Subjects ran at a constant speed of 8 km.h$^{-1}$ for 6 min at 3 different treadmill slopes (0%, 2.5% and 5%) on 6 separate occasions (at ages 13, 14, 15, 16, 21, and 27 years). At all three slopes, a significant decrease in VO$_2$ with increasing age was found for both males and females, implying a significant improvement in running economy for both sexes. As the males showed significantly higher submaximal oxygen uptakes than the females at all ages measured and for all 3 slopes it would appear that females have a better running economy than males. These results were strengthened after the same data was reanalysed using allometric modelling to account for the different individual body sizes.
That there are differences in running economy between children and adults is a well recognised fact (Rowland et al., 1988; Rowland and Green, 1988; Kanaley et al., 1989; Unnithan and Eston, 1990), but not all these differences have been systematically explored. There are a large number of variables that contribute to muscular efficiency, both biochemical and mechanical (Rowland, 1996). Several of these have been suggested as possible factors in age-related differences in running economy. These include: a greater stride frequency, inefficient running mechanics, body mass ratio, greater surface area, substrate utilisation, 'anaerobic capacity', and ventilatory efficiency (Rowland, 1989). Two factors that look particularly likely to have an influence on running economy during growth are a) the progressive decrease in the ratio of body mass to body surface area and b) the fall in stride frequency at a given running speed as leg length and height increase (Rowland, 1989).

2.5.3 Running economy and maturity

The influence of maturation on submaximal oxygen uptake during running in untrained males (n=97) and females (n=97) (mean age 12.2 years) was investigated by Armstrong et al. (Armstrong, 1999). Oxygen uptake (l.min⁻¹) increased at each exercise stage across all stages of sexual maturity (P<0.05). Once the effects of body mass were controlled using either ratio-scaling or allometry, no influence of maturity was observed. It was concluded that oxygen uptake is more likely to be related to body size than to size independent factors and that maturation has no influence on the oxygen uptake response to submaximal exercise.

In a further study, a longitudinal examination of the influence of growth and maturation on the development of oxygen uptake in untrained males (n=118) and females (n=118), mean age 11.2 ± 0.4 (SD) at the onset of the study, was undertaken by Welsman and Armstrong (2000a). Submaximal VO₂ (l.min⁻¹) responses were explained predominantly by changes in body mass and skinfold thicknesses, with no additional maturity-related increments. McMurray et al. (2002) had similar findings in a large longitudinal study of African-Americans (n=543) and Caucasians (n=1997), of whom 50.4% were female and 49.6% were male. The ages ranged from 8 – 16 years old. The higher relative VO₂ max (ml.kg⁻¹.min⁻¹) of the Caucasian youth when compared to the African-American youth was related to the lower body mass and skinfolds of the Caucasian youth.
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(McMurray et al., 2002). Multiple regression analysis revealed that the relative $\dot{V}O_2_{\text{max}}$ (ml.kg$^{-1}$.min$^{-1}$) during running was related to skinfolds, fat-free mass and resting energy expenditure. Age and developmental stage did not contribute significantly to $\dot{V}O_2_{\text{max}}$ (ml.kg$^{-1}$.min$^{-1}$) (McMurray et al., 2002).

In summary, mass-related submaximal oxygen uptake (ml.kg$^{-1}$.min$^{-1}$) at any given treadmill speed, declines with age in the untrained individual and appears to be related to changes in body composition and body mass with age, rather than to maturity. However, there have been no studies, to this author's knowledge, examining the relationship between maturation and running economy in elite adolescent male and female athletes.

2.5.4 Running economy and performance

As has been demonstrated above, endurance running performance improves year on year throughout the growth years (Daniels et al., 1978). These improvements in performance happen concurrently with an increase in running economy, as at any designated running speed the athlete/individual will be running at a lower percentage of their $\dot{V}O_2_{\text{max}}$ as they grow older (Rowland, 1996).

Whether it is possible to determine field endurance performance from submaximal running economy is still a matter for debate. Fay et al., (1989) investigated the physiological parameters related to distance running performance in female athletes. In particular the study looked at the relationship between running pace for the 5km, 10km, and 16.09 km (10 mile) race distances and oxygen uptake (running economy) at 3 submaximal treadmill speeds (196, 215 and 241 m.min$^{-1}$). Thirteen moderately to highly conditioned female runners aged 18 – 33 years volunteered to participate. This study found that running economy was only a moderate predictor of performance which was likely to be due to heterogeneity of the subjects both in training level and ability (Fay et al., 1989). In a study of high school (adolescent) male (n=11) and female (n=10) cross-country runners Femhall et al. (1996) evaluated the relationship between run performance and running economy. Laboratory tests were used to establish running economy. These were then analysed against the finish times (2 and 3 mile races, girls and boys respectively) at a cross-country meet. There was no difference in running
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economy between the girls and the boys. For the girls running economy ($r = -0.86$) was significantly related to performance, but not for the boys ($r = 0.10$) (Fernhall et al., 1996). The authors' could not explain these differences in findings for the boys and the girls, but often there is a greater heterogeneity in the results for female subjects providing the probabilities of higher correlation coefficients.

A combination of running economy and $\dot{V}O_2$ peak may provide a powerful performance indicator. The velocity at $\dot{V}O_2$ peak (ml.kg$^{-1}$.min$^{-1}$) can be regarded as a 'functional expression' of $\dot{V}O_2$ peak (ml.kg$^{-1}$.min$^{-1}$) because running economy characteristics are used to calculate the running speed that corresponds to $\dot{V}O_2$ peak (Almarwaey et al., 2003). This variable has been observed to be a powerful predictor of performance with adult runners (Billat and Koralsztein, 1996; Jones and Carter, 2000a). Almarwaey et al., (2003) found moderate to weak negative relationships ($r = -0.12$ to $-0.74$) with performance times for male and female adolescent athletes, which partially supports these studies (Almarwaey et al., 2003). Velocity at $\dot{V}O_2$ peak (ml.kg$^{-1}$.min$^{-1}$) has been shown, by these researchers, to be the most consistent and non-invasive variable that explains performance during middle distance running.

2.5.5 Running economy in elite and non-elite adolescents

There is a paucity of studies examining running economy in elite adolescent athletes when compared to their non-elite peers. Sjödin and Svedenhag (1992) undertook a longitudinal study to investigate the effect of endurance training on physiological characteristics during circumpubertal growth in young boys. Eight young runners (competitive status is unclear) were studied every six months for 8 years from the age of 12 years. Four other boys were untrained controls. The oxygen cost (ml.kg$^{-1}$.min$^{-1}$) of running at 15 km.h$^{-1}$ was consistently lower in the trained group of boys than in the untrained group and decreased with age in both groups (Sjödin and Svedenhag, 1992). After each individual's body mass scaling factor was calculated (oxygen uptake at 15 km.h$^{-1}$ expressed in ml.kg$^{-0.75}$.min$^{-1}$), running economy was shown to be consistently superior in the trained group but remained unchanged in both groups over the years studied (Sjödin and Svedenhag, 1992). Mayers and Gutin, (1979) found that elite pre-pubertal boys aged 8 – 11 years have been observed to have a lower submaximal
oxygen uptake (ml.kg\(^{-1}\).min\(^{-1}\)) when running at 5, 6, and 7 mph than non-runners of the same age. Because the elite boys were taller than the non-runners no significant difference was found in running economy after an analysis of covariance controlling for height was conducted between the groups (Mayers and Gutin, 1979).

Thus the limited available evidence suggests that running economy (ml.kg\(^{-1}\).min\(^{-1}\)) is superior in trained adolescent male athletes in comparison with non-athletes but there is no information available on running economy in trained or elite adolescent female athletes in comparison with non-athletic groups.

2.6 Blood lactate concentration during submaximal running

2.6.1 Introduction
Lactate is continuously produced in the skeletal muscles even at rest, but with the onset of exercise, increases in glycolytic resynthesis of ATP, result in a corresponding increase in the production of lactate (Armstrong and Welsman, 2007). Exercise performance can be predicted by blood lactate concentration and there a variety of measures that can be used to do this. In adults, a fixed blood lactate concentration of 4.0 mmol.l\(^{-1}\) and the corresponding intensity of exercise has been used to standardise the interpretation of the lactate responses in individuals. The use of the single blood lactate concentration of 4.0 mmol.l\(^{-1}\) as the standard was because this represented the maximum intensity at which an equilibrium between blood lactate accumulation and elimination occurs (Heck et al., 1985).

2.6.2 Blood lactate assay methods
There are several lactate assay methodologies in the literature, but the interpretation of the extant literature is complicated by methodological issues (Armstrong and Fawkner, 2007). Different methods of blood lactate analysis will not necessarily produce quantitatively similar results. Many paediatric laboratories now make use of automated enzymatic electrochemical analysers, such as those produced by Yellow Springs Instruments. These are very popular due to the small amount of sample blood required for the assay (usually < 25 \(\mu\)l of blood), the speed with which the results are produced (between 60 and 90 s), the immediacy of obtaining those results for feedback and data collection, and their simplicity of use. Prior to the development of these systems, blood
lactate analysis was carried out using manual enzymatic-fluorometric assays which require the preparation of a protein-filtrate (Maughan, 1982). These enzymatic-fluorometric assays have proven to be both reliable and accurate, but the time consuming nature of the pre-treatment of the samples and manual assay for lactate concentration has led to the automated and immediate analysis of fresh ‘whole blood’ samples becoming increasingly popular.

The variation in the results produced from these two different systems can be considerable and is dependent on two main factors (Armstrong and Fawkner, 2007). Firstly whether the solids in the sample (i.e. protein, cells etc) have been removed, and secondly whether the blood sample has been haemolysed to release erythrocyte lactate (Armstrong and Fawkner, 2007). In ‘whole blood’ assays the sample still contains the solid fraction when the lactate in the plasma fraction is assayed. In the Maughan (1982) method, on the other hand, the addition of a chemical lysing agent releases intracellular lactate, thus measuring total lactate, i.e. plasma lactate plus erythrocyte lactate. Lactate concentrations in whole blood are thus lower than those from preparations from which the blood solids have been removed. Lactate concentrations are about 30% higher in plasma than in whole blood (Armstrong and Fawkner, 2007).

Blood lactate response data are not comparable between assay techniques though there have been studies to compare the methods. Bruce et al (2001; unpublished) compared blood lactate concentrations determined by both the enzymatic electrochemical (YSI) method and the manual enzymatic fluorometric method (Maughan, 1982) using whole blood during cycling exercise and found no significant differences between the two (~1.3%) difference. Williams et al (1992) has determined a set of regression equations that can be used to estimate children’s blood lactate concentrations depending on the method employed. Interpretation of blood lactate concentration and inter-study comparison must take account of the assay method used. To obtain truly valid comparisons would require the same blood fraction to be analysed between studies. Unless otherwise stated, all blood lactate concentrations referred to in the following sections have been analysed using the whole blood enzymatic electrochemical (YSI) method to ascertain blood lactate concentration. However, throughout this thesis the Maughan (1982) method has been used.
2.6.3 Blood lactate during submaximal running and age
Children and adolescents accumulate less blood lactate during submaximal exercise than adults (Armstrong and Welsman, 2007). Research examining the relationship between age, and percentage of \( \dot{V}O_2 \) peak at blood lactate reference criteria are sparse and equivocal. Williams and Armstrong (1991), investigated the percentage \( \dot{V}O_2 \) peak at fixed blood lactate concentrations of 2.5 and 4.0 mmol.l\(^{-1}\) while treadmill running, in a large sample of boys (n=100) and girls (n=91) aged 11-16 years. There was no significant correlation of percentage of \( \dot{V}O_2 \) peak at 4.0 mmol.l\(^{-1}\) in either sex at any chronological age. A significant, but negative relationship was found between chronological age and percentage of \( \dot{V}O_2 \) peak at 2.5 mmol.l\(^{-1}\) for boys \((r= - 0.226, P<0.05)\) and girls \((r= - 0.272, P<0.05)\) (Williams and Armstrong, 1991). Tolfrey and Armstrong (1995) investigated the corresponding exercise intensity at fixed blood lactate concentrations of 2.5 and 4.0 mmol.l\(^{-1}\) in prepubertal boys \((n=26)\) aged 11.1 \((\pm 0.4)\) years, teenage boys \((n=26)\) age 14.1 \((\pm 0.3)\) years, and men \((n=23)\) aged 22.4 \((\pm 2.7)\) years. No differences were found in percentage \( \dot{V}O_2 \) peak at the 2.5 mmol.l\(^{-1}\) level between any of the groups. For both the prepubertal and the teenage boys a significantly higher percentage \( \dot{V}O_2 \) peak at 4.0 mmol.l\(^{-1}\) blood lactate concentration was observed when compared to the men (Tolfrey and Armstrong, 1995). In contrast, Welsman et al., (1994) observed no significant relationships between age and percentage \( \dot{V}O_2 \) peak at either 2.5 or 4.0 mmol.l\(^{-1}\) in untrained males \((n=50)\) aged 12 – 16 years when undertaking an incremental treadmill running exercise.

2.6.4 Blood lactate during submaximal running and maturity
Because children grow and mature at very different rates, individuals of the same chronological age may vary considerably in their actual biological age. It is important therefore that interpretation of the exercise responses of children and adolescents should consider the stage of maturity that they have attained at the time of testing. Eriksson et al., (1971), using testicular volume, in 13-15 year old boys \((n=8)\), as the indicator of maturation stage, hypothesised that the ability to produce lactate during exercise was highly dependent on sexual maturation as there was an ‘almost significant’ correlation between maximal muscle lactate attained and the testicular volume index (Eriksson et al., 1971).
The influence of sexual maturity on the percentage \( \dot{V}O_2 \) peak at fixed blood lactate concentrations of 2.5 and 4.0 mmol.l\(^{-1} \) was examined during discontinuous treadmill running to exhaustion in boys and girls aged 11 – 16 years (Williams and Armstrong, 1991). Analysis of variance revealed no significant differences in any of the lactate variables examined with progression at each Tanner stage of maturity (Williams and Armstrong, 1991). Welsman et al., (1994) did not find any relationship between serum testosterone and percentage \( \dot{V}O_2 \) peak at 2.5 and 4.0 mmol.l\(^{-1} \) in 12 – 16 year old boys (n=50) during incremental treadmill running. These findings were supported by Tolfrey and Armstrong (1995) who found no significant differences in percentage \( \dot{V}O_2 \) peak between pre-pubertal and teenage boys at 2.5 mmol.l\(^{-1} \), leading them to the conclusion that factors other than maturation during puberty influence blood lactate responses to exercise (Tolfrey and Armstrong, 1995).

2.6.5 Blood lactate during submaximal running and performance
The ‘lactate threshold’, although a criticized term by many physiologists, has been widely accepted as a predictor of endurance performance in adults (Pfitzinger and Freedson, 1997b), with some studies using 2.0 mmol.l\(^{-1} \), 2.5 mmol.l\(^{-1} \), and 4.0 mmol.l\(^{-1} \) as fixed lactate concentrations to represent the ‘lactate threshold’ and other studies use the ‘inflection point’ of the lactate-intensity curve; and others use 1 mmol.l\(^{-1} \) above baseline to represent ‘lactate threshold’. Training results in a lower blood lactate concentration at any given exercise intensity (Bird and Davidson, 1997).

Tanaka (1986) investigated the relationship between running velocity at blood ‘lactate threshold’ (as determined by visual inspection of the blood lactate concentrations plotted against mean running velocities) and running performance (50m, 40 s and 5 min) in boys (n=30) aged 14 years at puberty and young men (n=30) aged 16 – 20 years and found that lactate threshold only correlated significantly with the distance covered in 5 min \((r=0.644)\) (Tanaka, 1986). Oxygen uptake at a blood lactate concentration of 4.0 mmol.l\(^{-1} \) was found to be an important determinant of cross-country run performance in high school running teams, (race distance 3 and 2 miles, boys and girls respectively), adolescent boys \((r=-0.74)\) and girls \((r=-0.77)\) aged 16.5 ± 0.9 and 16.0 ± 0.9 respectively (Fernhall et al., 1996).
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Almarwaey et al (2003) examined the relationship between competitive 800m and 1500m performance times and several variables including percentage VO₂ peak at fixed blood lactate concentrations of 2.0 mmol.l⁻¹, 2.5 mmol.l⁻¹, and 4.0 mmol.l⁻¹ in sub-elite endurance-trained boys (aged 14.8 – 17 years) and girls (aged 14.9 – 17.6 years). Percentage VO₂ peak at 2.5 mmol.l⁻¹ was an important independent variable \((r=0.51)\) for 800m performance in the boys (Almarwaey et al., 2003). Almarwaey et al. (2003) suggested that a fixed blood lactate concentration of 2.5 mmol.l⁻¹ may be the concentration of choice if a single blood lactate variable is to be used to monitor and assess middle distance running performance in young people. The authors' (Almarwaey et al., 2003) rationale for suggesting that 2.5 mmol.l⁻¹ fixed blood lactate concentration be used for monitoring purposes is that this level appears to represent the maximum exercise intensity at which equilibrium between blood lactate accumulation and elimination occurs in young people (Williams and Armstrong, 1991).

2.6.6 Blood lactate during submaximal treadmill running in elite and non-elite adolescents

Very few studies have directly compared elite and non-elite adolescent athletes. However, some valuable information is available in studies examining just one of these groups. For example, a blood lactate concentration of 4.0 mmol.l⁻¹ has been shown to correspond to 91 ± 5% and 89 ± 5% of VO₂ peak in male and female teenage high school cross-country runners (age 15 – 18 years) (Fernhall et al., 1996).

Almarwaey et al., (2004) conducted a study to identify the exercise intensity (percentage VO₂ peak ) that corresponds to maximal lactate steady state, where the change in blood lactate concentration between 10 and 20 min was < 0.5 mmol.l⁻¹ in both male and female endurance trained adolescent runners aged 16.5 ± 0.8 and 16.7 ± 0.9 years respectively. The percentage VO₂ peak at maximal lactate steady state (2.7±1.3 mmol.l⁻¹ [males], and 2.3±0.5 mmol.l⁻¹ [females]) was 85±8% and 85±2% in endurance trained male and female runners respectively and was the same percentage of VO₂ peak as that for blood lactate concentrations of 2.0 and 2.5 mmol.l⁻¹ (Almarwaey et al., 2004).
In a longitudinal study of circumpubertal boys (n=8), Sjödin and Svedenhag (1992) examined blood lactate concentration during submaximal running in relation to age at peak height velocity and compared the results against a matched for age cohort of untrained controls (n=4). All the boys were around 12 years old at the commencement of the study. The running velocity corresponding to a blood lactate concentration of 4.0 mmol.l\(^{-1}\) improved significantly from 4.23 m.s\(^{-1}\) at peak height velocity - 2 years, to 4.77 m.s\(^{-1}\) at peak height velocity at +4 years in the training group between the ages of 12 and 18 years. No change was observed in the untrained group in the same period (3.89 - 3.60 m.s\(^{-1}\)) (Sjödin and Svedenhag, 1992).

Thus, while the blood lactate concentration of trained boys appears to be lower than untrained boys at submaximal running intensities, there are no studies examining the blood lactate response to running in trained and untrained female adolescents.

### 2.7 Power Output

#### 2.7.1 Introduction

Children are more often engaged in short bursts of high intensity activities than in long-term activities, with the average duration of these activities being around 6 s for low to medium intensity activities and 3 seconds for the high intensity activities with the average interval between the short bursts of activity being about 20 s (Bailey et al., 1995a). Thus it is surprising how little research has been done on this area in paediatric exercise science. Short-term muscle power is a fundamental aspect of many ‘multiple sprint’ sports such as jumping events, basketball, volleyball, rugby, ice hockey, and racquet sports to name but a few.

Power is the product of force and velocity and can be defined as the ability to work, the capacity for performance, the rate of transfer of energy (Åstrand et al., 2003b). Power is measured in watts and is the rate of doing work (Åstrand et al., 2003a). Power production during instantaneous (peak) power exercises or tests is limited by the rate at which energy is supplied (adenosine triphosphate [ATP] production) for the muscle contraction (ATP utilisation), i.e. the rate at which the myofilaments can convert...
chemical energy into mechanical work (Van Praagh and Doré, 2002). Mean power output (e.g. over a 30 second period) however, has a fairly high aerobic fraction in pre-pubescent and adolescent boys, when compared with young adult males (Van Praagh and Doré, 2002). Anaerobic power is the maximal anaerobic ATP per second yield by the whole organism, during a specific type of short-duration, maximal exercise (Green, 1994). Muscle power is the ability of the neuromuscular system to produce the greatest possible impulse in a given time period. When compared to adults, children are not always able to put themselves under stress, particularly in laboratory conditions. Short-term muscle power or peak power is defined as the highest mechanical power that can be delivered during exercise of up to 30 s duration, depending on the force or load against which the individual is working and how the acceleration is organised (Van Praagh and Doré, 2002).

Short-term power output has two main components; peak power output, which can be defined as the maximum rate at which energy is transferred to the external system, and mean power output, which is the total work done during the test divided by the time taken (Lakomy, 1994). The fatigue index is another measurement that is calculated. This is the difference between the peak power and the lowest value at the end calculated relative to the peak power.

Cycle ergometer tests are the most common method of measuring peak power output. Only cycling ergometry (or rowing ergometry) allows precise measurement of peak power output independent of body mass as the imposed resistive load (Van Praagh and Doré, 2002). One of the most commonly used tests for investigating power output in children and adolescents is the Wingate test (Bar-Or, 1987) which is a maximal 30 s sprint test commenced from a fast rolling start without the resistive mass applied, leading to errors in the calculation of power. More recent maximal 30 s cycle ergometer sprint tests (Lakomy, 1986) account for the angular kinetics of the flywheel during acceleration allowing power to be calculated accurately.

2.7.2 Power output, body mass and age
Peak power (W) as well as peak power relative to body mass (w.kg⁻¹) increases with age throughout the entire growth period. Absolute peak and mean power output from a Wingate test performance was positively related to age in both males (n= 306) and
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females (n=70) and the relationship between power and age was stronger for lower limbs than for upper limbs. However, even when normalised for body mass, the power that a 9 year old boy produced is still only 70 – 80% of that generated by a young adult male (Inbar and Bar-Or, 1986; Inbar and Chia, 2008). Falgairette et al. (1991) observed mean power in a Wingate test to increase from 4.7 W.kg\(^{-1}\) at age 6-8 years to 7.6 W.kg\(^{-1}\) at age 14-15 years in a group of boys (n=144). Even after controlling for muscle mass, lean body-mass or active muscle cross-sectional area the adult-child differences persist (Malina and Bouchard, 2004). Thus, as explained by Inbar and Chia (1996, 2008), these age related differences in power output and the continuous, albeit slower increase in mass adjusted power cannot be simply put down to differences in body-size or active muscle mass (Inbar, 1996). Factors such as neural activation and intramuscular coordination are suggested to have additional and significant roles in the development of this component of human fitness (Inbar and Chia, 2008).

2.7.3 Power output and maturity

Falgairette et al. (1991) investigated the effect of sexual maturity on power output during cycle ergometer sprinting in a group of boys (n=144) aged 6 – 15 years. Sexual maturity was determined using salivary testosterone as an objective indicator. Significant relationships were found between peak power and mean power with age, height, mass and salivary testosterone concentration, (all \(P<0.01\)). From 6 - 8 to 11 - 12 years there were very small changes in the mean testosterone values. Thereafter, testosterone values increased sharply and significant correlations were observed between both peak power (W.kg\(^{-1}\)) and mean power (W.kg\(^{-1}\)) and testosterone; the authors concluded that the increases in mean power (W.kg\(^{-1}\)) were due to an increase in muscle mass relative to total body mass resulting from both androgenic and non-androgenic hormones and changes in muscle characteristics (Falgairette et al., 1991).

The influence of sexual maturity on performance in a 30 s maximal cycle sprint was investigated in untrained males (n=100) and females (n=100) aged 12.2 ± 0.4 years (Armstrong et al., 1997). Maturation was assessed using Tanner's indices of pubic hair and, in the boys, salivary testosterone. Whilst there were no sex differences detected for either peak power or mean power, significant main effects for maturation were found for both peak power and mean power expressed in W, W.kg\(^{-1}\), or with body mass
controlled using allometric principles. Interestingly, testosterone did not increase the variance in peak power or mean power explained by body mass alone, and was not correlated with blood lactate. Thus, sexual maturation was found to exert an influence on peak and mean power independent of body mass (Armstrong et al., 1997).

The same cohort were re-tested a year later and used multi-level regression modelling to examine the influence of sex, growth and maturational influences on power output (Armstrong et al., 2000). Body mass, skinfold thickness, chronological age and sex were significant covariates of peak and mean power. However there were no maturity effects detected in this study, somewhat confounding the earlier study of this cohort (Armstrong et al., 1997; Armstrong et al., 2000). Five years later the same cohort were retested (tested at 12, 13 and 17 years of age). Multi-level regression modelling was again used to analyse the data. Body mass and skinfold thickness were significant influences on both peak and mean power outputs; age exerted a positive but non-linear effect on power output independent of body size and fatness. Maturity did not have a significant effect (Armstrong et al., 2001). De Ste Croix et al. (2001) who had very similar findings, also used multi-level modelling to investigate the influence of age, sex, body size, skinfold thicknesses, maturity, thigh muscle volume and leg strength on power output during a 30 s maximal cycle sprint in males (n=15) and females (n=19) who were aged 10.0 ± 0.3 years at the initial testing and 11.8 ± 0.2 years at the second testing. No significant differences between the sexes or maturity effects were observed for either peak or mean power output. Thigh muscle volume was found to exert a positive influence on power output, which was additional to the effects of body mass, sum of skinfolds and age (De Ste Croix et al., 2001).

In summary, power output increases with age, from childhood throughout adolescence, whether it is expressed in absolute terms or in relation to body mass. There is evidence to suggest that body mass, sum of skinfolds and thigh muscle volume, with an independent effect of age, are significant factors explaining the development of power output in young people. Maturation does not appear to have a significant role in the development of power output in young people.
2.7.4 Power output in elite and non-elite adolescents

There is very little research examining the differences (if any) in short-term power output, between elite and non-elite/untrained children and adolescents. Recently, Bencke et al., (2002) in a large study which drew subjects from the best sporting clubs in Denmark, investigated the possible effects of specificity of training on muscle strength and short-term power in children from different sports (swimming, tennis, team handball, or gymnastics) in relation to growth and maturation status. Within each sport the coach divided the young athletes into either elite or non-elite groups according to their performance level and talent. There were 44 elite and 43 non-elite boys and 51 elite and 47 non-elite girls. Most of the differences in power output between the young people from different sports disappeared when the data were normalised in relation to body mass. The researchers concluded that while there might be some influence of training specificity, that power was related more to muscle size than to training. Sexual maturity was assessed in this investigation but did not appear to have been included in the analyses. There was no true control group as all the subjects were active sports participants even if they had not been categorised as elite by their coaches. Thus there is a dearth of information relating to short-term power output in elite adolescent male and female athletes and particularly regarding the significance of power output for performance in sport.

2.7.5 Post sprint blood lactate concentration

Lactate is continuously produced in the skeletal muscle, with the onset of exercise increases in the glycolytic synthesis of ATP result in a correspondingly greater production of lactate in the active fibres (Armstrong and Fawkner, 2007). Although there are problems with the comparison of blood lactate across studies due to methodological issues following a single 30 s maximal cycle sprint in adults there is a strong relationship between blood and muscle lactate concentration (Cheetham et al., 1986).

During a test such as a cycle ergometer sprint, blood lactate rises progressively as lactate diffuses from the muscles into the blood. When the test ends the lactate continues to diffuse into the blood and accumulates until the rate of removal from the blood exceeds the rate of diffusion (Chia and Armstrong, 2007). The dynamics of post exercise blood sampling were demonstrated by Chia et al.,(1997). Twenty five girls and
twenty five boys (mean age 9.7 ± 0.3 years) each completed a 20 s and a 30 s maximal cycle sprint. Blood was sampled every 30 s for 3 minutes following the maximal cycle sprint. Blood lactate was observed to rise in boys from a baseline value of 2.0 mmol.l⁻¹ to 3.2 mmol.l⁻¹ after 30 s, peak 2 min post exercise at 3.6 mmol.l⁻¹ and then fall to 3.1 mmol.l⁻¹ after 3 min. In girls the corresponding values were 16., 3.7, 4.9 and 4.7 mmol.l⁻¹ respectively (Chia et al., 1997). As it is not always possible to collect serial blood samples a single sample taken at 2 min post exercise can be assumed to reflect peak values in young children, however this is not the case with adults, whose peak occurs at around 5 min post exercise (Chia and Armstrong, 2007) or in high quality athletes at around 10 min post exercise (Nevill et al., 1996). Evidence examining blood lactate concentration post sprint across a range of ages is sparse. Falgairette et al., (1991) investigated blood lactate levels at 2 min post Wingate anaerobic test in untrained boys aged between 6 and 15 years. Blood lactate concentration increased by around 64% between the ages of 9 and 10 to 13 years, from 6.3 mmol.l⁻¹ to 8.4 mmol.l⁻¹ respectively.

Williams et al (1994) investigated the relationship between sexual maturation and blood lactate concentration with a 30 s maximal cycle sprint. A total of 185 children, 97 boys (12.0 ± 0.3 y) and 88 girls (12.5 ± 0.4 y) performed a 30 s maximal cycle test. No significant main effects of sex or maturity for post exercise blood lactate values were found. In contrast to this, blood lactate concentrations 2 min post performance of a Wingate test increased from 5.5 mmol.l⁻¹ and 6.2 mmol.l⁻¹ at 6 to 8 years of age to 8.4 mmol.l⁻¹ at 13 years respectively in untrained but active males and was significantly associated with salivary testosterone (r=0.38) which was being used as a marker for maturity in this study (Falgairette et al., 1991).

In summary, while the blood lactate concentration following sprinting increases during childhood there are no studies examining blood lactate concentration post sprinting in elite (national or international standard) adolescent male or female athletes compared to their non-elite or untrained peers. Furthermore the effects of age and maturity on the blood lactate response to sprinting have hardly been investigated.
2.8 Strength Measures

2.8.1 Introduction
Strength can be defined as the ability of the muscles to exert force either for the purpose of resisting or moving external loads (including the body) or to propel objects against gravity (again including the body) (Blimkie and Macauley, 2000). Muscle strength is an important component of fitness that is essential for the undertaking of many tasks associated with normal daily living throughout the normal lifespan (Beunen and Thomis, 2000). The study of the development of strength in children and adolescents is complicated by the fact that, as with so many other physiological parameters, muscle strength is a “multi-faceted, performance related fitness component that is underpinned by muscular, neural and mechanical factors” (De Ste Croix, 2007). Strength is a key component of many aspects of performance but the difficulty in measuring muscle strength, either as an internal force exerted or as an external force, is mainly as a result of a lack of physiological markers to determine a maximal effort (De Ste Croix, 2007).

A further confounding factor in the analysis of strength measures is the method of strength testing employed by the investigators. Many investigators use isometric strength tests such as hand-grip strength. Isometric muscle action occurs when there is no change in the length of the muscle whilst developing tension – in other words the limb involved is completely static. More recently, isokinetic strength testing has become popular. Isokinetic muscle action occurs when the muscle shortens or lengthens at a constant velocity whilst developing tension, i.e. whilst the limb is moving. Isotonic exercise is commonly used when testing the amount that can be lifted during one repetition (1 RM) and where the external load remains constant. Isotonic muscle action occurs where the muscle develops tension against a resistance that remains constant throughout a range of motion.

2.8.2 Strength, body mass and age
Strength characteristics generally follow the growth curve that is observed for most body dimensions (Beunen and Thomis, 2000). Therefore, in boys, static and explosive strength, and upper body muscular endurance, all increase during an adolescent growth spurt that occurs between 3 months to 1 year after peak height velocity (Beunen and
Thomis, 2000). This is not as evident in girls as a less obvious adolescent growth spurt is observed for strength (Beunen and Thomis, 2000).

Early studies showed that muscular strength is related to height and body mass, and that height, in particular is a useful indicator of differences in strength in pre-adolescent children. Factors relating to the strength of adolescent post-pubertal males (n=53) were examined by Watson and O'Donovan (1977). A strength index composed of left and right hand grip (isometric) and back strengths was related to anthropometric measurements and their derivatives; habitual activity levels; body shape as defined by Heath-Carter and Sheldonian somatotypes ratings; and anthropometric ratios. Strength was found to be positively related to all anthropometric measurements with the exception of skinfold thicknesses. When body mass was held constant, strength was positively related to arm circumference, bicondylar diameters of the humerus and femur, thigh volume, and biacromial diameter, and negatively related to the percentage of body fat. Measurements related to muscle size such as upper arm and thigh volume appear to make the largest individual contributions to predictions of strength, though bone diameters also have an independent contribution (Watson and O'Donovan, 1977).

This study found that the strength of post-pubertal adolescent males was determined primarily by parameters of body size, but that body shape had an important influence (Watson and O'Donovan, 1977). Most of the cross sectional data examining isokinetic strength in children and adolescents has demonstrated a significant increase in strength with age in males and females (De Ste Croix et al., 2003). However although age had a strong effect on strength development, rates of maturation and anatomical growth varied and their effects on strength did not correlate with chronological age (De Ste Croix et al., 2003). A longitudinal study that used multi-level modelling, demonstrated that in children aged 10-14 years old, age was a non-significant explanatory variable once mass and stature were taken into account (De Ste Croix et al., 2002).

Strength has been reported to be related to body size and muscle mass with associations ranging from 0.30 to 0.60. The highest associations have been found between 13 and 15 years, which may reflect the variation in the timing of the adolescent growth spurt (Malina et al., 2004b). It is generally agreed that there is a steady increase in strength with size, with little difference between boys and girls until they reach puberty,
although boys have consistently higher single and double hand grip scores than girls (Blimkie, 1988). At puberty both sexes have a significant increase in the speed of strength gain (Jones and Round, 2008). At puberty boys increase to a much greater final strength than girls and have a disproportionate increase in the musculature of the upper limb which is nearly double that of young women when they reach final strength (Jones and Round, 2008). Girls appear to have very little increase in strength once they reach adolescence, with their rate of increase in strength during the pubertal years being very similar to the rate of increase in strength during the pre-pubertal years (Blimkie, 1988).

### 2.8.3 Strength and maturity

The effect of sexual maturation on muscle strength is characterised by the increased levels of testosterone and growth hormone that are a typical part of the endocrine adaptations that take place during puberty (De Ste Croix, 2007). Testosterone concentrations increase by around 4 times during early puberty to a rapid increase of around 20 times in mid-to-late puberty (Tanner Stage 3). Testosterone has been shown to stimulate anabolic processes in skeletal muscle and appears to be the hormone primarily responsible for the development of strength (De Ste Croix, 2007). The development of elbow flexor (biceps) and knee extensor (quadriceps) strength in boys (n=50) and girls (n=50) was followed longitudinally from the age of 8 to 18 years (Round et al., 1999). At peak height velocity sex differences emerged and were particularly marked for the biceps. Data for individual children were aligned to peak height velocity and associations between height, body mass, circulating testosterone and strength were investigated using multi-level modelling. In girls, quadriceps strength was proportional to height and body mass, whilst in boys, testosterone was an additional explanatory factor. However testosterone was not fully able to explain the differences in biceps strength between boys and girls and the authors conclude that some additional factor promotes biceps growth in boys during puberty. The increase in testosterone in the boys began to rise one year before peak height velocity and increased steadily, reaching adult levels at around three years post peak height velocity. The increase in testosterone coincided with the divergence of strength between boys and girls (Round et al., 1999). Round et al (1999) concluded that for girls the development of quadriceps strength is proportional to the general increase in height and body mass, and that for the girls' biceps a negative age term was required in addition to height and body mass,
indicating that the girls' biceps did not grow in strength in proportion to body mass and height (Round et al., 1999).

2.8.4 Strength and performance
The simplest of tasks, such as running or jumping are dependent on a combination of strength and coordination and their interaction with the biomechanics of the musculoskeletal system (Jones and Round, 2008). Strength to body mass ratio would appear to be a crucial factor in tasks such as running and explosive jumping, however while running speed and jumping performance improve steadily throughout childhood, the ratio of isometric strength to body mass remains constant or decreases slightly until puberty (Jones and Round, 2000). Changing muscle length may be responsible for this. Isometric strength is not dependent on muscle length but the velocity of shortening is directly proportional to the number of sarcomeres in series which will increase roughly in parallel with height. Faster muscle means that greater forces can be generated at high speeds thus generating larger amounts of power which will enable the muscle to produce a greater impulse to the ground when jumping or when moving a longer limb at the same angular velocity to impart a greater momentum to the hand or foot when throwing or kicking (Jones and Round, 2008).

2.9 Psychological Profile

2.9.1 Introduction
Modern society places an ever increasing emphasis on competition and achievement which has led to considerable research on understanding achievement behaviour in sport; the ability to understand why some athletes are driven to succeed, are eager to push themselves in spite of adversity and difficult challenges, persist and exert consistent hard effort to achieve their goals, when others avoid competition, don't try hard and give up very easily (Harwood et al., 2008).

2.9.2 Achievement Goal Theory
Achievement goal theory was developed in the mid-1980s by researchers primarily working in educational settings. John Nicholls' (1984) theoretical approach to achievement goals has been the basis for much of the research into achievement goal
Achievement behaviour is defined as behaviour that is directed at developing and demonstrating high ability as opposed to low ability. Ability can be looked at in two ways, both of which share the notion that task mastery is improved by effort or learning and that mastery is not normally lost (Nicholls, 1984). Firstly, levels of ability and task difficulty can be judged as high or low when compared in relation to the individual’s perception of their mastery, understanding and performance. When examined in this light, gains in mastery indicate competence. The more individuals feel they have learned, the more competent they feel (Nicholls, 1984). Secondly, task difficulty and ability can be defined as high or low relative to that of others in the same reference group as the individual. Examined in this context a gain in mastery does not necessarily demonstrate high ability. In order to demonstrate high ability the individual must achieve more, with less or equal effort, to others for an equal performance. High ability means above average and low ability means below average (Nicholls, 1984).

These two types of ability, as identified by Nicholls (1984) are the basis for the achievement goals that are used by people to define success in a task. When people are task involved, gains in personal mastery of a task or skill give them a sense of competence (Harwood et al., 2008). Task involved people feel a sense of personal achievement when they feel that they have learnt or improved whilst undertaking a task. On the other hand, ego involved people gain their sense of competence by demonstrating to others that their performance is either superior, or has achieved the same result to others with less effort expended (Harwood et al., 2008). Different facets of ‘self’ are focused on by these two differing achievement goals. A task involved individual focuses primarily on the development of self, regardless of others around them. An ego involved person is mainly focussed on comparing their perceived ability with reference to others around them, and by demonstrating this ability (Harwood et al., 2008). Thus, achievement goals define the meaning that individuals give to achievement settings and situations. An individual’s definition of success and failure, their motivational processes and reactions, and subsequent motivated behaviours such as task choice, persistence and effort can all be defined within the structure of these goals (Harwood et al., 2008).
2.9.3 Beliefs about the causes of success
Duda and Nicholls (1992) investigated the beliefs about the causes of success in school and sport of 207 high school students. They were interested to see if the goal belief dimensions previously revealed in classroom work would also exist for sport. The study also aimed to compare, for school and sport, the relationships among goal orientations, perceptions of ability and intrinsic satisfaction with the activity, particularly as satisfaction with schoolwork had been found not to correlate highly with perceived ability or ego orientation, but had been found to correlate moderately highly with task orientation (Duda and Nicholls, 1992). Competition is an integral and defining feature of sport and thus it was expected that a moderate association between perceived ability and ego orientation was likely to be displayed, primarily due to the fact that it is unlikely that ego-oriented individuals who have a low perceived ability would see many opportunities to demonstrate superiority in a sports setting. Therefore only those who perceive themselves as competent are likely to have a high ego orientation in sport (Duda and Nicholls, 1992). Task orientation and perceived ability in sport was also expected to be highly correlated – in direct contrast to the classroom setting. The results of this study were that for sport there was a belief that success requires high ability and the task orientation goal was associated with beliefs that success requires effort, interest and collaboration with peers (Duda and Nicholls, 1992). From this early work, initially in education and then in sport, there flowed a huge amount of research into the personal, interpersonal and environmental influences on athlete behaviour in achievement settings (Harwood et al., 2008).

2.9.4 Psychological Skills
Strategies such as mental imagery and goal setting are, arguably fundamental to coping with the demands of high level sport. The motivational profile of an athlete may be key to the degree with which they actually make use of mental preparation strategies (Harwood et al., 2003). Harwood et al. (2003) examined Imagery use in a large number (n=88 male and n=202 female) elite adolescent sports participants with a mean age of 16.6 ± 1.5 y. The young athletes completed the Perceptions of Success Questionnaire (POSQ) (Roberts et al., 1998) to assess their dispositional goal orientations and the Sport Imagery Questionnaire (Hall et al., 1998) to assess frequency and function of Imagery use. Athletes with higher task/higher ego goal orientations used significantly
more Imagery, regardless of the function than athletes with lower task/moderate ego or athletes with moderate task/lower ego orientations.

Harwood et al. (2004) then went on to examine the motivational profiles and reported psychological skills and strategies usage of 573 young elite athletes (males n = 174, females n=395, unreported gender n=4) from a wide variety of sports, age range 14 – 20 y and a mean age of 17.6 y. Harwood et al. stated that ‘in elite level sport, effort investment is virtually a natural requirement if one seeks to demonstrate personal improvement (task) and normative superiority (ego).’ Therefore they expected that the young elite athlete with higher levels of both goal orientations would be likely to invest in and report greater use of psychological skills both in practice and in competition. Initial results showed that males reported having a higher ego orientation than females; that males used the skill of Relaxation during competition more frequently than females and that males used Self-Talk during competition more often than females. Further analysis revealed that there was a bias towards a larger proportion of the male sample to be moderate to higher ego orientated. Athletes with a higher task/moderate ego profile reported greater use of Imagery, Goal-Setting, and Self-Talk in practice and in competition in comparison with athletes with a moderate-task/lower-ego profile. The researchers concluded that the findings supported the importance of a high-task orientation as the higher the task orientation the greater the reported skill use, with the exception of Relaxation which was limited in its use across all the groups. The use of Goal-Setting in practice was the same between those athletes with high-task/moderate-ego and those with moderate-task/lower-ego orientation (Harwood et al., 2004).

2.9.5 Psychological Instruments

2.9.5.a The Perceptions of Success in Sport Questionnaire

The Perceptions of Success in Sport questionnaire was developed by Roberts and Balague (1991) specifically to measure goal orientation in sport contexts with effort and ability. Roberts et al., (1998) found that “task and ego goal orientations are associated with different beliefs about the wider purposes of sport”. A belief that sport develops social responsibility and life skills is significantly associated with task orientation, whilst an ego orientation is predominantly related to the belief that sport is a means to
an end, such as an enhanced social status, wealth and popularity (Duda, 1989; Roberts and Ommundsen, 1996).

2.9.5.b The Test of Performance Strategies (Thomas et al., 1999)
The Test of Performance Strategies instrument was devised to assess eight psychological strategies used in practice (activation, automaticity, emotional control, goal-setting, imagery, attentional control, relaxation and self-talk) and eight strategies used in competition (the same strategies except that attentional control is replaced with negative thinking). The Test of Performance Strategies was developed to provide a sound general measure of psychological skills that could be used for individual assessment purposes and also to assess the effects of psychological skills training programmes upon skill development (McCann, 1995). Prior to the development of the Test of Performance Strategies the psychological skills training literature emphasised the use of psychological skills in competition and ignored their use in practice; as committed (adult) athletes can spend up 99% of their time in training (Duda and Nicholls, 1992) they are likely to be using psychological skills during practice as well. Thomas et al., (1999) set out to remedy this omission with the development of this instrument.

2.9.5.c The Beliefs About the Causes of Success Questionnaire (Duda and White, 1992; White and Zellner, 1996)
The Beliefs About the Causes of Success questionnaire has been adapted for sport from the original instrument which was developed in education (Guay et al., 2000). This instrument asks the athletes to respond to the stem “what do you think is most likely to help athletes do well or succeed in sport?” The available responses reflected beliefs such as “athletes succeed if they have the right equipment”; “athletes succeed if they have the right equipment”; “athletes succeed if they are natural born athletes” and “athletes succeed if they use performance enhancing drugs”. The scale reflects whether the athletes believe that effort or ability is the more important factor in their success.

2.9.5.d The Situational Motivation Scale (Guay et al., 2000)
The Situational Motivation Scale is an instrument that measures the type of motivation that an individual experiences when they are currently engaging in an activity (Ryan and Deci, 2000b; Ryan and Deci, 2000a). Self-determination theory has been developed
over the last thirty years by Ryan and Deci (Treasure, 2001). This theory posits that human beings are driven by three innate psychological needs; the needs for competence, autonomy, and relatedness (social belonging) and are considered essential for understanding the what and the why of goal pursuits. Competence is central to achievement motivation. The need for autonomy (or self-determination) is crucial to the formation of motives. For an individual to experience choice and freedom autonomy needs to be satisfied. When autonomy is satisfied choice and freedom are then experienced and the individual’s behaviour is regulated by intrinsic or identified structures (Guay et al., 2000). Intrinsically motivated behaviours are those that are undertaken for their own sake, for the satisfaction gained from performing them (Deci, 1971). Extrinsic motivation refers to behaviours that can be subdivided into two different types as defined by self-determination theory. External regulation occurs when the individual undertakes the behaviour in order to gain a reward or to avoid a negative consequence. Identified regulation refers to behaviours that are valued and perceived as being chosen by the individual themselves, however the motivation is still classed as extrinsic because the activity is performed as a means to an end rather than simply for itself (Guay et al., 2000). There is a third type of motivational concept that Deci and Ryan (1985) (Deci and Ryan, 2000) identified, that is, amotivation. When an individual is amotivated they have no sense of purpose and no expectations of reward or the possibility of changing the course of events. Amotivation has been likened to learned helplessness, a feeling of incompetence and expectations of uncontrollability of the outcome (Harwood et al., 2005). The Situational Motivation Scale is designed to assess all three types of motivation in an athlete.

2.9.5.e The Individual Sport Motivated Climate Scales (Harwood et al., 2005)
The Individual Sport Motivated Climate Scales is a new instrument currently being developed and undergoing validation at Loughborough University. This instrument is designed to provide a comprehensive and holistic measure of the motivational climate for individual sport types in the competition environment (Harwood et al., 2005). The instrument investigates the motivational climate surrounding the athlete with particular reference to five separate sub-scales which target the task and ego involving perceptions of the young individual sport athlete with respect to the behaviours, attitudes, values and
evaluation processes of the coach, the father, the mother, the peers and the evaluation structure of the sport itself (Thomas et al., 1999). Thus the instrument arrives at an overall measure of the motivational climate surrounding the young athlete.

2.10 Summary

Young successful male athletes in many sports tend to be earlier maturers in comparison with their non-athletic contemporaries. In females, some sports, particularly those that require a more lean and lithe build for aesthetic reasons, such as gymnastics, will favour the late maturer. However, there is a dearth of information regarding the maturity status of the elite adolescent female athlete. Longitudinal and cross-sectional research has shown that peak oxygen uptake is higher in male adolescent athletes when compared to their untrained counterparts, but again, there is very limited information on the female adolescent athlete. Running economy is superior in trained adolescent male athletes but no studies have examined running economy in the female adolescent athlete in comparison with her non-athletic peers. The blood lactate concentration of trained boys appears to be lower than untrained boys at submaximal running intensities, but there are no studies examining the blood lactate response to running in trained and untrained female adolescents. There is a dearth of information relating to short-term power output in elite adolescent male and female athletes and particularly regarding the significance of power output for performance in sport. Whilst it is known that blood lactate concentration following sprinting increases during childhood and adolescence there are no studies examining blood lactate concentration post sprinting in elite (national or international standard) adolescent male or female athletes compared to their non-elite or untrained peers. Furthermore the effects of age and maturity on the blood lactate response to sprinting have hardly been investigated. The investigation of the psychological profile of the adolescent elite athlete has shown that there is some use of psychological skills amongst the top performers, but there is a need for far more research examining the psychological factors contributing to success in elite adolescent athletes. Finally, there is a dearth of information regarding the psychological skills usage of the elite female adolescent athlete in comparison with non-elite peers.
3.1 General Introduction

This chapter details the procedures and methods that were employed during the experimental studies described within this thesis. All of the tests described in the following chapters were carried out in the laboratory facilities of the School of Sport and Exercise Sciences at Loughborough University. The Loughborough University Ethical Advisory Committee approved the methods described here prior to the commencement of data collection. All procedures were carried out according to the methods laid down in the 'Code of Practice for Workers having Contact with Body Fluids'. All researchers who were involved in the administration of the tests described were Criminal Records Bureau approved prior to involvement in the studies.

3.2 Participant Recruitment

The female elite adolescent athletes in this study were deemed elite by virtue of attendance at a National Governing Body of Sport training camp or/and being a member of their sport's national squad or/and competing in a national or international event. The control or non-elite group were all active girls who participated and sometimes competed in sports at school and local level. The term ‘athlete’ in this review and throughout the thesis is used to refer to a sportsperson in serious training for any sport. The participants who volunteered to participate in the studies described in this thesis were recruited from schools in Nottinghamshire, Derbyshire and Leicestershire who responded to a letter sent to every Specialist Sports College within a 35 mile radius of Loughborough University (Appendix A). Some of the elite young sports performers who participated in these studies, in addition, were recruited whilst attending Nike© Summer Performance Camps at Loughborough University. All of these young sports
performers had been selected for National or Regional Squads by their respective National Governing Bodies.

All of the young sports performers and their parents, guardians or care-givers were given in writing, detailed information about the relevant study which gave the rationale for the study and detailed the specific requirements of the study, the procedures and techniques involved and any possible risks and discomforts. (Appendix 2). All the procedures were also verbally explained to the young sports performers. Every effort was made to ensure that each individual sports performer and their parent(s), guardian(s) or care-giver(s) had a complete understanding of what their involvement in the study would entail. If an individual then decided that she wished to participate in a particular study and her parent, guardian or care-giver were also willing for her to participate then they both signed a statement of informed assent and consent respectively (Appendix 3). When the individual arrived in the laboratory they then completed a health history questionnaire in the presence of a researcher for clarification purposes (Appendix 4).

3.3 Preliminary Measurements

In each of the studies described in the following chapters the participants completed the preliminary measurements as detailed below.

3.3.1 Measurement of body mass and stature
Stature was determined to the nearest 0.1 cm using a stadiometer (Holtain Ltd., Crymych, U.K.). Participants were instructed to stand with their heels together against a metal plate with their feet at approximately 60°. The researcher ensured that the participant’s buttocks and back of her head were in contact with the vertical backboard of the stadiometer. The participant stood erect but relaxed as the stadiometer headboard was brought down to rest on the superior aspect of the head with sufficient pressure to compress the hair. In order to compensate for any shrinkage in the intervertebral discs gentle traction was applied to the mastoid processes. The stature was then read off the stadiometer scale. Body mass was measured to the nearest 0.1 kg using a balance beam (Model 3306ABV, Avery Industrial Ltd., Leicester, U.K.). Participants were dressed in t-shirts and shorts without shoes.
3.3.2 Self-assessment of sexual maturity
Each participant was asked to make a self-assessment of secondary sexual characteristics (Morris and Udry, 1980) by observing Tanner's photographs of the stages of secondary sex characteristics (Tanner, 1962). For female participants these consist of representations of 5 stages of breast development (frontal and lateral) and pubic hair development. After explanation of procedures by a same-sex researcher participants entered a private, lockable, room with a full length mirror and viewed the photographs and written explanations carefully participants then marked an 'A' on the form next to the photograph that most reflected their current stage of development and a 'B' next to the photograph reflecting their next closest stage. The form was placed into an envelope by the participant and sealed before leaving the room and handing the envelope to the researcher. The participants were assured of complete confidentiality and anonymity. The right to refuse consent was also stressed.

3.3.3 Skinfold Measurement
Skinfold measurements were taken from the right-hand side of the body in accordance with the International Society for the Advancement of Kinanthropometry (ISAK) guidelines (Marfell-Jones et al., 2006) in a private room, by the same researcher, using a Harpenden calliper (John Bull, British Indicators Ltd., U.K) and recorded to the nearest 0.2 mm. All the anatomical landmarks used to locate the skinfold sites are as defined by ISAK and can be found in the current ISAK manual (Marfell-Jones et al., 2006).

The Triceps skinfold was taken from a vertical skinfold raised on the posterior aspect of the triceps muscle, exactly half way between the anatomical landmarks acromiale and radiale when the hand is supinated. The Biceps measurement was taken from a vertical skin fold raised on the anterior aspect of the arm in the mid-line at the level of the mid acromiale-radiale landmark (at the same horizontal level as the triceps skinfold). The Subscapular skinfold measurement was made by palpating the inferior aspect of the scapular and raising a skinfold approximately 1 cm below taken with the natural fold of skin running obliquely downwards. The Supraspinale skinfold site (previously known as the Suprailiac (Durnin and Womersley, 1974) was located at the intersection of the line from the marked iliospinale to the anterior axillary border and the horizontal line at the level of the marked iliocristale. The skinfold was raised running obliquely and medially downward at a 45° angle as determined by the natural fold of the skin. The Abdominal skinfold was taken vertically at a point 5 cm horizontally to the right hand
side of the midpoint of the navel. The Anterior Thigh skinfold site was situated at the mid-point between the Inguinal point and the Patellare. The skinfold was taken with the participant sitting with their torso erect, their arms/hands supporting their hamstrings and the leg extended. The skinfold is raised on the marked site parallel to the long axis of the thigh. Participants who have particularly tight skinfolds were asked to assist by lifting the underside of the thigh. The Medial Calf skinfold site was measured on the most medial aspect of the calf at the level of the maximal girth with the fold parallel to the long axis of the leg. The participant stood and placed their right foot on a box. The right knee was bent at about 90°.

3.3.4 Girths and Circumference Measurements
Girths and circumferences were taken during the same measurement session as the skinfolds. The Waist circumference was measured at the circumference of the abdomen at its narrowest point between the lower costal border (10th rib) and the top of the iliac crest, perpendicular to the long axis of the trunk. The participants were instructed to breathe normally and the measurement was taken at the end of a normal expiration. The Gluteal (hip) measurement was taken at the point of the greatest posterior protuberance of the buttocks perpendicular to the long axis of the trunk. The Thigh measurement was taken 1 cm below the Gluteal fold site, perpendicular to its long axis. The Calf measurement was taken at the level of the Medial Calf skinfold site, perpendicular to the long axis of the leg. For all the circumference measurements the participants were asked to stand with their feet apart and weight evenly distributed on each foot. Participants did not wear shoes during measurements.

3.4 Laboratory Tests
3.4.1 Equipment
The submaximal incremental treadmill running test to determine oxygen uptake and blood lactate concentration during running and the uphill peak oxygen uptake test were both performed on a motorised treadmill (Runner® Galaxy M.J.C. MTC Climb 2000, Bianchia and Draghetti Sac, Cavezzo, Italy). The 30 s maximal sprint test was performed on a friction loaded cycle ergometer (Monark 864, Vansbro, Sweden). The cycle ergometer was linked to a BBC Micro-Computer (BBC, Model B, Acorn Computers, UK) which allowed for instantaneous power output, corrected for flywheel acceleration, to be monitored and recorded accurately. The performance data was
averaged over 1 s intervals. The equipment and programme have been described in
detail by Lakomy (1986).

3.4.1.1 ‘Calibration’ of the treadmill.
Prior to the studies described in chapters 5 and 8 the velocity of the unloaded treadmill
belt was checked against the digital reading given by the treadmill display against a
range of suitable speeds. The length of the treadmill was established prior to these
measurements (4.078 m). One hundred revolutions of the treadmill belt were timed and
the actual belt speeds were then calculated.

3.4.1.ii Calibration of the cycle ergometer.
Prior to each testing session in the studies described in chapters 6 and 8 the relationship
between the flywheel external angular velocity and the output from the generator and
the A-D converter was calibrated. The ergometer was pedalled for around 100 s at 60
rev.min⁻¹ and pedal revolutions were counted. The deceleration time of the flywheel for
three different loads (1 kg, 2 kg, and 3 kg) was also determined by pedalling in excess
of 120 rev.min⁻¹, ceasing pedalling, and recording the time it took the flywheel to stop.
These measures enabled a linear regression equation of load against flywheel
deceleration to be obtained, from which the ‘accelerating balancing load’ could be
calculated (for a full explanation see Lakomy, 1986).

3.4.2 Familiarisation with treadmill running
Before the start of treadmill testing all participants were familiarised with the testing
procedures and with treadmill walking and running. This occurred whether or not the
participants had indicated that they were familiar with using a treadmill. The
familiarisation process consisted of the participant walking on the treadmill until they
were confident and comfortable (usually around 2 – 3 minutes) followed by running at a
treadmill speed of 8 km.h⁻¹ until they were fully comfortable (around 2 – 3 minutes).
Participants were instructed in the performance of an ‘emergency stop’. The
participants were then fitted with a nose-clip and mouthpiece and practiced putting these
on and taking them off whilst stationary. The participants were familiarised with the
Rating of Perceived Exertion (RPE) scale. Finally the participants ran at 8 km.h⁻¹ and
practiced putting on the nose-clip and mouthpiece and using the RPE scale whilst
running.
3.4.3 Submaximal incremental treadmill running

In the studies described in chapters 5 and 8 each participant performed an incremental treadmill test comprising 4 min stages of increasing exercise intensity to determine the submaximal blood-lactate concentration and the submaximal oxygen uptake of each participant (Fig. 3.1).

![Figure 3.1 Schematic representation of submaximal incremental treadmill running.](image)

Participants began running at 8 km.h⁻¹ with no incline on the treadmill. The running speed of the subsequent stages was 9 km.h⁻¹ and 10 km.h⁻¹. If participants were able to carry on past these first three stages they then ran at 12 km.h⁻¹ and then 14 km.h⁻¹. Heart rate (beats.min⁻¹) was continuously monitored throughout the test using short-range telemetry (S610 Polar Electro oy, Kempele, Finland; sampling frequency 15 seconds). Expired air samples were collected for 60 seconds using the Douglas Bag method during the fourth minute of exercise at each intensity. Inspired gas volumes were calculated using the Haldane transformation and the oxygen uptake, production of carbon dioxide, minute ventilation and respiratory exchange ratio were all subsequently calculated. The participant’s rating of perceived exertion was noted towards the end of the expired air collection period using the 20 point Borg scale (Borg, 1962). As the collection of expired air was completed the participant stopped running by placing her feet on the side rails of the treadmill. The researcher immediately collected duplicate capillary blood samples from the participant which were then stored on ice. The
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participant’s heart rate at 30 s after stopping was recorded and the treadmill speed increased to the next level, at which point the participant started to run again. The test was halted when the researcher deemed that the participant was running close to, but not at the maximal speed that she could sustain for 4 minutes.

3.4.4 Peak oxygen uptake (Peak \( \dot{V}O_2 \) test)

In the studies described in Chapters 5 and 8 peak oxygen uptake (Peak \( \dot{V}O_2 \)) was determined in all participants in a continuous progressive, incremental uphill treadmill test to voluntary exhaustion (Figure 3.2). The reliability of this test in adolescents was determined by Hemmings (2006 pp 57-65) in a study of 7 males (13.6 ± 0.7 years) and 11 females (13.3 ± 0.5 years). The relationship between the test – retest values for the peak oxygen uptake raw data was \( r=0.93, \ P<0.01 \), the co-efficient of variation was 3.2% and there was no significant difference between test 1 and test 2 (\( P=0.97 \)). The researcher selected a belt speed which elicited a heart rate of around 170 beats.min\(^{-1}\) during the submaximal treadmill test, the initial gradient was set at 3% in order to achieve voluntary exhaustion in 8 – 12 min, but participants ran for as long as possible. The belt speed remained the same throughout test but the incline was increased every 3 min by a further 2%. Heart rate (beats.min\(^{-1}\)) was continuously monitored throughout the test using short-range telemetry (S610, Polar Electro oy, Kempele, Finland; sampling frequency 15 s) and RPE (Borg, 1962) was recorded towards the end of each stage. Expired air samples were collected toward the end of each stage and were subsequently analysed (see Chapter 5). Participants kept on running until they indicated that they could exercise for only a further 60 s. At this point the final collection of expired air was made and the test was then ended. Throughout the test strong verbal encouragement was given. Peak \( \dot{V}O_2 \) was considered to be that achieved in the last minute of exercise and was deemed to have occurred when at least two of the following criteria were achieved; 1) peak recorded heart rate greater than 95% of age predicted maximum (220 – age); 2) a peak respiratory exchange ratio (RER) value greater than unity; 3) subjective signs of fatigue (e.g. inability to keep pace with the treadmill, facial flushing, hyperpnoea, dyspnea, and unsteady gait).
3.4.5 Expired air analysis
During an expired air collection participants wore a nose-clip and air was collected in a Douglas Bag (Harvard® Apparatus, Cambridge). Participants breathed through a low resistance respiratory valve (Jakeman and Davies, 1979) and 30 mm wide bore, resistance tubing (Falconia flexible ducting, Baxter, Woodhouse and Taylor Ltd., Macclesfield, UK.) into previously evacuated 150 litre capacity Douglas bags (Plysu Protection Systems, Milton Keynes, U.K.). The concentration of oxygen and carbon dioxide in the expired air samples was determined using a paramagnetic oxygen analyser (Servomex® 1440, Crowborough) and an infrared carbon dioxide analyser (Servomex® 1440, Crowborough). Each analyser was calibrated before each testing occasion using certified reference (nitrogen / oxygen-carbon dioxide) gases (CyroService Ltd., Worcester, U.K.). The volume and temperature of the expired air were determined by the means of a Harvard dry gas meter (Harvard® Apparatus, Cambridge, U.K.), which was also calibrated prior to testing using a syringe of known volume, which had been fitted with an electronic thermistor and logger (Edale Systems, Milton Keynes, U.K.).

Figure 3.2 Diagrammatic representation of the peak oxygen uptake protocol used in the studies described in Chapters 4, 5 and 8.
Instruments Ltd., type 2984, Model C). Barometric pressure was established using Fortin Barometer (F.D. and Company, Watford, U.K.).

3.4.6 Maximal 30 s cycle ergometer sprint
External leg power of the participants was determined using a 30 s maximal cycle ergometer sprint (Figure 3.3) for the studies described in Chapters 6 and 8. The reliability of this test was determined by Hemmings (2006 pp 57-65) in a study of 7 males (13.6 ± 0.7 years) and 11 females (13.3 ± 0.5 years). The relationship between the test—retest values for the peak power output raw data was $r=0.90$, $P<0.01$, the coefficient of variation was 5.6% and there was no significant difference between test 1 and test 2 ($P=0.36$). The same ergometer was used for all sprints. The saddle height was adjusted so that there was slight flexion of the knee at the lowest point in the pedalling cycle. All subjects completed a standardised warm up consisting of 30 s cycling at 80 rev.min$^{-1}$, followed by a 30 s rest and then cycling at 110 rev.min$^{-1}$ against a 1 kg resistive mass. The 30 s cycle sprint commenced 5 min after the standardised warm-up, from a rolling start against minimal resistance (weight basket supported). When a constant pedal rate of 60 rev.min$^{-1}$ was achieved, the command “3-2-1 GO” was given, the computer was started and the resistive mass of 0.07 kg.kg$^{-1}$ was applied simultaneously.

Finger prick blood samples were taken at 3 min post-warm-up and at 2 and 5 min post-sprint to determine blood lactate concentration. All participants were given strong verbal encouragement throughout the test.
3.4.7 Strength Testing on the Concept2 Dyno®

A specially designed ergometer, (Concept2 Dyno®) was used to measure upper and lower body strength and the results were expressed in kg.

3.4.7.i Single and Combined Leg Push:

The participant sat upright on the forward facing seat with her hands clasping the hand rails under the seat and her back in contact with the back rest. She placed her right foot onto the foot plate of the Dyno® and she was instructed to put her left leg out at an angle to the seat, with the heel down and the toe up (this was to minimise the ability of the participant to use their opposing leg to assist in the leg push). The participant was then instructed to slowly draw her right leg towards her body with her foot still in contact with the foot plate. She then pushed the foot plate away as hard as she could, she then slowly drew the foot back towards her ready for the next push. This was repeated three times as a warm-up. The participant then repeated the procedure three more times and the best score of three pushes was recorded. The whole procedure was then repeated for the left leg and then again for both legs pushing together. There was a 10 sec rest between pushes. At all times the participant was reminded to keep her back against the back rest and her hands clasping the hand grips under the seat of the Dyno®.
3.4.7.;; Arm Push:

From the same seated position on the Dyno® the participant was instructed to put both legs out at an angle in the same position adopted for the single leg push test. The push bar was adjusted to be at chest height for the participant. The participant was instructed to sit upright and to keep her back against the back rest. She then put her hands onto the push bar at a comfortable distance apart (usually about shoulder width) and followed the same procedure as for the leg push test, with three warm-up pushes and then 3 test pushes, with a 10 sec rest between pushes, with the best score of the three being recorded.
3.4.7.iii Arm Pull:
The participant moved to the other end of the Dyno® to perform this test. She sat with her chest up against the rest and her legs crossed behind and under her (again to stop any assistance in the arm-pull from the legs). The participant clasped the handles of the arm pulls and was instructed to pull through with her elbows going past her body and bringing her hands to chest level. The same procedure as earlier, of three warm-up pulls followed by three test pulls, with a 10 sec rest between pulls, the best score of the three being recorded was followed.

![Figure 3.7 Arm Pull on a Concept2 Dyno® ©Concept2](image)

3.5 Blood collection, storage and analysis
Blood collected during the studies described in this thesis was analysed for lactate concentration. All the analyses described in this thesis were carried out in the laboratories of the School of Sport and Exercise Sciences at Loughborough University. All the blood collected for the studies in this thesis was collected from duplicate capillary blood samples taken from the fingertip of the participant. Prior to collection the participant’s fingertip was wiped clean with a Steret Isopropyl Alcohol mediswab 70% v/v (Medlock Medical Ltd., Oldham, U.K.) and then dried with a tissue. The finger was then pricked using a Unistick® 3 Comfort single use safety lancet (Owen Mumford Ltd., Oxford, U.K.). Blood was collected using duplicate 20 μl glass micropipettes (Blaubrand® intraMARK. Brand GMBH, Wertheim, Germany). The first drop of blood was discarded before collection commenced. The blood was de-proteinised by dispensing into two previously prepared chilled 1.5 ml microcentrifuge tubes (Fisherbrand®, Thermo Fisher Scientific Inc., Loughborough, U.K.) each containing 200 μl 0.4 mol·l⁻¹ (−2.5%) perchloric acid. The microcentrifuge tubes were stored in ice until the end of testing. They were centrifuged at 13000 revs.min⁻¹ for 3 min and then frozen in a −20° freezer. Analysis was carried out using the ‘Fluorimetric assay for the determination of blood lactate’ method (Maughan, 1982) [Appendix L].
3.6 Psychological Profiling

All participants were asked to complete a series of psychological questionnaires (see below). The aim of the questionnaires was to establish a 'psychological skills profile' of young performers whilst training and competing in their sport whether it be at elite or school level.

3.6.1 TOPS – Test of Performance Strategies.

(Thomas et al., 1999) (Appendix H). This is a 64 item questionnaire designed to look at the psychological strategies and skills used by sports performers. TOPS examines 'activation', 'relaxation', 'imagery', 'goal-setting', 'self-talk', 'automaticity' 'emotional control' and 'negative thinking / attentional control skills' both in training and competition. The young performers rated the frequency of their use of a particular skill on a scale of 1 (never use) to 5 (always use).

3.6.2 ISMCS – Individual Sport Motivated Climate Scales (Appendix I).

This is an unpublished, partially validated profiling tool, in development at Loughborough University. Its' authors are Jonathan M. J. Smith and Dr C.G. Harwood. The scale looks at the motivational climate of the performer and has been specifically designed to look at the motivational climate for those participating in individual sports rather than team sports. The CCS is divided into two sections, A and B. Section A looks at the young performer's relationships with their coach; their father; their mother; their peers; and the reward structure of their sport. Section B aims to find out which areas are important to the young performer.

3.6.3 SIMS – Situational Motivational Scale

(Guay et al., 2000) (Appendix K) This is a 16 item measurement of the constructs of intrinsic motivation, identified regulation, external regulation and amovitation that might be demonstrated by a performer. The participants were asked to respond to a series of questions about the reasons why they were currently engaged in their sport [scale of 1 (not at all) to 7 (exactly)]. Analysis of responses enables the motivation for a performers participation in sport to be established.

3.6.4 BASQ – Beliefs About the causes of Success Questionnaire

(White et al., 2004) (Appendix J) This is a 12 item measurement of the performer's beliefs about the causes of success. The analysis of the results enables the researcher
to assess what part the young performer feels that the constructs of effort and ability play in their success in sport. The young performers were asked to respond to a series of statements on a scale of 1 (strongly disagree) to 5 (strongly agree).

3.6.5 POSQ - Perception Of Success Questionnaire (Appendix L): This is a 12 item measurement of task and ego orientation. Participants were asked to respond to a series of statements on a scale from A (strongly agree) to E (strongly disagree). The analysis of the responses given enables the task and ego orientation of the performer to be assessed.
Elite Athlete Subsets
The elite athletes were subdivided into 4 groups for the purpose of analysis. The divisions, sports involved and ‘n’ of each sport are detailed in Table 3.1 below.

Table 3.1 Elite athletes by subset.

<table>
<thead>
<tr>
<th>Sport Type</th>
<th>Short Term</th>
<th>N=</th>
<th>Sports in Subset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Endurance</td>
<td>IE (n=16)</td>
<td>11</td>
<td>Distance-Running</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>Swimming</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>Biathlon</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Triathlon</td>
</tr>
<tr>
<td>Individual</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Games</td>
<td>IG (n=15)</td>
<td>12</td>
<td>Badminton</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Squash</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>Tennis</td>
</tr>
<tr>
<td>Individual</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>IO (n=19)</td>
<td>4</td>
<td>Athletics–Track</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Athletics–Field</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>Golf</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>Gymnastics</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>Karate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Sculling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Tae-Kwando</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>Windsurfing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>Fencing</td>
</tr>
<tr>
<td>Team Players</td>
<td></td>
<td>11</td>
<td>Rugby</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Volleyball</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>Water-polo</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Basketball</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>Cricket</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>Hockey</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>Football</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>Lacrosse</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>Netball</td>
</tr>
</tbody>
</table>
3.7 Statistical analyses
Data are presented as the mean and the standard error of the mean and are based on the subject populations mentioned. A variety of statistical procedures were used including independent t-test, One-way analysis of variance; two-way analysis of variance (ANOVA), repeated measures (ANOVA). Data were checked for homogeneity of variance. Effect size was computed manually for the psychological analyses using equations supplied by Field (2005a). Post-hoc was used where appropriate using Bonferroni or Tukey. The statistical programme SPSS v.14 for Windows, (SPSS Inc. Chicago, Illinois, U.S.A) was used for all the above statistical computations. Longitudinal data was analysed using the multilevel modelling program MLwiN 2.10 (Rasbash et al., 2005). A linear additive multilevel model structure was employed. Two levels of hierarchical observational units were the number of visits at level 1 (within individuals) and the sample of adolescents (between individuals) at level 2. A more detailed description of the procedures used in each study is given in the appropriate chapter. Data are presented as mean and standard error of the mean, and are based on the subject populations stated,
Chapter 4  Maturation and Body Composition

CHAPTER 4
Maturation and Body Composition in Elite and Non-Elite Female Adolescent Athletes

4.1 Introduction

Adolescence is a period of dynamic physical and biological change. The variations in physical growth and maturation of a child have a profound effect on their physical activity, physical fitness and physical performance (Rowland, 2005). Measuring these changes in young people is a complex and sensitive issue as it encompasses not just the physical growth of the child into an adult, but also their sexual maturation, a process that is highly varied in rate, tempo, and timing from one individual to another (Malina and Beunen, 2008). It is important to differentiate between growth and maturation as the individual differences in physical growth and maturation can have an influence on the performance of young athletes. Young athletes who are successful in sport tend to differ in maturity status and rate of growth and maturation from the general population (Beunen and Malina, 2008). This may be due to a number of factors; young athletes are often selected on their size and physique, the definition of ‘athlete’ is wide, particularly at junior level and can encompass a wide range of physical skills and differing levels of competition and growth and earlier maturation are both associated with performance at least in males (Beunen and Malina, 2008). The fact that competition for children and adolescents is run in chronological age-bands in many sports also favours those athletes who are early maturers and also those who are born at the start of the selection year (Simmons and Paull, 2001), although it must mentioned that nearly all of the studies on which these comments have been based have used male subjects.

Growth is defined as a ‘quantitative increase in size and mass’, such as increases in height or weight (Bogin, 1988) Growth refers to the increase in size of an individual. As a child grows they become heavier and taller and increase and change their proportions of lean and fat tissue, with boys gaining primarily in muscle mass and skeletal tissue, and girls, whilst experiencing an increase in muscle mass and skeletal
mass, experience a continuous rise in fat mass (Baxter-Jones and Sherar, 2007). The organs of both sexes increase in size. Different parts of the body grow at different times and at different rates (Baxter-Jones and Sherar, 2007).

In exercise science the most commonly used indicators of size are stature and body mass. Where body composition is considered, it is often viewed as relative fat free or lean mass and relative fat mass. During adolescence the relative adiposity of males declines, be they athletes or non-athletes, with male athletes having less adiposity than inactive adolescents. In female athletes relative adiposity does not increase as much with age as it does in non-athletes. Thus the difference in adiposity between female athletes and female non-athletes is greater than the corresponding trend for males (Malina, 1994a).

Skeletal age, sexual (secondary sex characteristics) and age at peak height velocity (PHV) are the methods most commonly used to assess the progress of an individual through biological maturation (Malina, 1994a). Biological maturation is defined as “a progression of changes that lead from an undifferentiated or immature state to a highly organised, specialised and mature state” (Bogin, 1988) and has also been described as referring to the “tempo and timing of progress toward the mature state, (i.e. menarche and development of secondary sexual characteristics)” (Baxter-Jones and Helms, 1996). Functional maturation occurs biologically when procreation and raising of offspring, who will then go on to procreate themselves, occurs (Cameron, 2003). Biological maturity can be defined by the chronological age at peak height velocity (Baxter-Jones and Sherar, 2007). Biological maturity age at peak height velocity is said to be 0.0 years. If an individual reaches peak height velocity at the age of 15 years then their biological maturity age when their chronological age is 13 years would be -2.0 years. This then enables individuals to be identified as early, average or late maturers according to when they reach peak height velocity. Early maturers are those who reach peak height velocity more than 1 year earlier than the mean age and late maturers would be those who attain peak height velocity more than 1 year after the mean age (Baxter-Jones and Sherar, 2007). Age at peak height velocity can only be accurately determined by regular and frequent longitudinal measurements that commence during the prepubertal phase. In girls, peak height velocity is usually reached at around 12 years of
age (Baxter-Jones and Sherar, 2007) though the recorded age range is from 9.2 to 15.0 years (Malina et al., 2004c). Boys, in contrast reach peak height velocity at around 14 years of age (Baxter-Jones and Sherar, 2007) with an age range of 12.0 years to 15.8 years (Malina et al., 2004a).

Skeletal maturity is commonly held to be the most accurate method of assessing biological maturation (Malina et al., 2004c), because the maturation of the skeleton spans the entire period of growth from foetus to adult. However, in order to use this method of assessment of maturity it is necessary to x-ray the hand and wrist of the individuals being assessed in order to measure the bone structure and shape, which places extra ethical and cost considerations on researchers, although the amount of radiation that a child would be exposed to per screening is less than that they would receive during an aeroplane flight to Europe (personal communication, Johnson, 2008).

Sexual maturation is a continuous process from the embryonic stage of the foetus through childhood and puberty to the attainment of full sexual maturity and fertility (Malina et al., 2004c). Assessment of sexual maturity in studies of youth and adolescents is based on the development of the secondary sexual characteristics during puberty. The most commonly used method for assessment of the development of secondary sexual characteristics is the use of the Tanner Indices for pubic hair development (boys and girls), breast development (girls), and genital development (boys) (Tanner, 1962). These characteristics are either assessed by an especially trained person, usually a medical doctor or a nurse, or the individuals are asked to perform a self-assessment of maturity using the appropriate standardised Tanner charts showing either photographs or drawings. In females the age at menarche is a commonly used factor for defining biological maturation. Menarche provides a well known indicator of gonadal maturation for individual girls (Onat and Ertem, 1995), and is defined as the first menstrual flow (Malina, 1983). Onset of menarche is closely associated with peak height velocity in the majority of girls (Baxter-Jones and Sherar, 2007), occurring, on average about a year after peak height velocity (Geithner et al., 1998).

In some sports later mean ages of menarche have been reported in elite performers when compared with non-elite performers (Malina, 1983; Baxter-Jones and Maffulli, 2002).
In the United Kingdom, Baxter-Jones and Helms (1996) reported that girls in the Training of Young Athletes study (n=222, Gymnasts n=81, Swimmers n=60, Tennis players n=81) had a later mean age of onset of menarche (obtained using recall during a semi-structured interview), than the United Kingdom reference value of 13 years. The British study's cohort were coach-nominated athletes and generally regarded as being elite athletes, in that they were all being intensively trained, (thresholds as defined by each sport's national governing body), and/or that they had achieved or were expected to achieve performance success to a specified level (Baxter-Jones et al., 1993). In Poland however, female pupils at sports schools, or who were classed as active in sports, showed no significant difference in the age of onset of menarche when compared with their non-active contemporaries (Malina et al., 1997b;Geithner et al., 1998). The Malina et al., (1997) study obtained the age of onset of menarche from their participants (n=102) using either prospective or retrospective (by questionnaire) analysis. The Geithner et al., (1998) Polish study obtained age at menarche prospectively (the girls were interviewed about their menarcheal status at each visit) from their participants (n=49). The Polish cohorts, in both studies, who were classed as being active in sports were undergoing systematic training of around 12 hours a week (Malina et al., 1997b;Geithner et al., 1998) although none of these girls were classed as elite athletes. None of the reported studies examined body composition.

Thus there is a paucity of research and equivocal findings regarding the growth, maturation and body composition of elite adolescent female sports performers compared to non-elite adolescent female sports performers. The purpose of the current study was to examine the physical growth, sexual maturity and body composition of the elite adolescent female sports performers and their non-elite colleagues and to test the hypothesis that the elite females will be less sexually mature and have a leaner physique than their age matched non-elite peers.

4.2 Methods

Eighty six elite and 100 non-elite adolescent females of between 12 and 17 years of age volunteered to take part in the study. The elite performers either attended summer performance camps with their respective national training squads at the time of testing or were recruited from specialist sports schools and colleges in the counties of
Nottinghamshire, Leicestershire and Derbyshire. The non-elite participants were recruited from schools local to Loughborough and also from the specialist sports schools and colleges mentioned above. Written informed consent and assent was sought prior to involvement by parent/guardian and/or caregiver and participant respectively, for the studies, which were approved by Loughborough University Ethical Committee. A more detailed description can be seen in Chapter 3. The elite athletes were analysed as an entire cohort but were also split down into 4 subsets which reflected the type of sport that they took part in. These 4 subsets were ‘individual endurance - IE’, ‘individual game players - IG’, ‘individual others - IO’, and ‘team players- T’. The full breakdown of the sports and the ‘n’ involved in each subset is detailed in section 3.7 of Chapter 3, General Methods. ‘Individual endurance’ was the group that contained the endurance athletes in the cohort, mostly distance runners, with a long course swimmer, a biathlete and some triathletes. ‘Individual game players’ encompassed the racket sports, badminton, tennis and squash. ‘Individual others’ held a wide variety of athlete types, from athletics–track, athletics–field, karate and tae Kwando, all the way to windsurfing, fencing and single sculling. The ‘team players’ had most of the team games represented; rugby, football, lacrosse, hockey, netball, basketball, volleyball.

4.2.1. Physical Characteristics
Age was calculated from the date of birth and the date of the test. Stature was measured to the nearest 0.1 cm and body mass to the nearest 0.1 kg. All participants were asked to perform a self-assessment of maturity by assessing their secondary sexual characteristics according to Tanner’s (1962) indices of secondary sex characteristics. Self-assessment has proved to be a reliable and valid method for obtaining this data (Duke et al., 1980; Claessens et al., 2000; Leone and Comtois, 2007; Morris and Udry, 1980). A more detailed account of the procedure can be seen in chapter 3.

4.2.2 Onset of Menarche
Age of onset of menarche in girls and their mothers was obtained by retrospective questionnaire (Appendices C & E) Generally most teenage girls are able to recall their age of menarche within a range of 2 to 3 months, making the variable sufficiently accurate for group comparisons (Malina, 1983). Recall data is influenced by error in recall, though various studies over the years have reported validity of recall with
reasonable accuracy (Bean et al., 1979; Hediger and Stine, 1987; Koo and Rohan, 1997; Malina et al., 2004).

4.2.3 Statistics
Descriptive statistics were calculated for elite and non-elite participants by age and by maturational status. Differences between the elite and non-elite participants were examined using two way (age x group) and (maturity x group) analysis of variance (ANOVA). An independent t-test was used to examine the difference in age of onset of menarche in elite and non-elite participants and also in their mothers. A one-way ANOVA was used to examine the elite athlete subsets as detailed above. Results are expressed as mean ± standard error of the mean.

4.3 Results

4.3.1 Physical characteristics of elite and non-elite female adolescent sports performers compared by age

The mean ages of the adolescent females who participated in the study are shown in Table 4.1. There were no significant differences in age between the elite and non-elite girls in any of the age groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>12 years</th>
<th>13 years</th>
<th>14 years</th>
<th>15 years</th>
<th>16 years</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite</td>
<td>12.7±0.1 (6)</td>
<td>13.4±0.5 (15)</td>
<td>14.5±0.4 (21)</td>
<td>15.5±0.4 (23)</td>
<td>16.4±0.5 (21)</td>
<td>NS Group</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>P&lt;0.01 Main Effect Age</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>12.8±0.7 (11)</td>
<td>13.6±0.5 (23)</td>
<td>14.5±0.4 (22)</td>
<td>15.4±0.4 (31)</td>
<td>16.5±0.5 (13)</td>
<td></td>
</tr>
</tbody>
</table>
The physical characteristics of the elite and non-elite adolescent female sports performers by age group and by maturation stage are shown in Tables 4.2 and 4.3. There were no significant differences between the elite and non-elite girls for either body mass or stature when analysed by age group or by maturation stage.

Table 4.2 Body Mass (kg) and stature (cm), for elite and non-elite adolescent female sports performers by age group. Group numbers are indicated by the figure in the brackets (mean ± SE).

<table>
<thead>
<tr>
<th>Group</th>
<th>12 years</th>
<th>13 years</th>
<th>14 years</th>
<th>15 years</th>
<th>16 years</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite</td>
<td>40.0±1.9 (6)</td>
<td>50.4±2.1 (14)</td>
<td>57.2±2.0 (21)</td>
<td>57.5±1.4 (23)</td>
<td>63.8±1.5 (21)</td>
<td>NS Group P&lt;0.01 Main Effect Age</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>48.8±3.3 (11)</td>
<td>54.4±2.9 (23)</td>
<td>56.8±2.0 (22)</td>
<td>56.3±1.2 (31)</td>
<td>58.7±2.6 (13)</td>
<td>P=0.074 Age x Group</td>
</tr>
<tr>
<td>Stature (cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td>1.55±0.01 (6)</td>
<td>1.61±0.02 (14)</td>
<td>1.68±0.02 (21)</td>
<td>1.65±0.01 (23)</td>
<td>1.65±0.03 (21)</td>
<td>NS Group</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>1.58±0.02 (11)</td>
<td>1.63±0.01 (23)</td>
<td>1.65±0.01 (22)</td>
<td>1.64±0.01 (31)</td>
<td>1.64±0.01 (13)</td>
<td>P&lt;0.01 Main Effect Age</td>
</tr>
</tbody>
</table>
There was a main effect of age [Table 4.2] for body mass and stature (P<0.01) with the older girls being heavier and taller than the younger girls. There was a main effect of maturation [Table 4.3] for body mass and stature (P<0.01) with the more mature girls being heavier and taller than the less mature girls.

Table 4.3 Body mass (kg), stature (cm) and age (y) for elite and non-elite adolescent female sports performers by Tanner stage (PH) (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Tanner Stg 2 Body Mass (kg)</th>
<th>Tanner Stg 3</th>
<th>Tanner Stg 4</th>
<th>Tanner Stg 5</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite 45.7±3.0 (11)</td>
<td>52.6±2.3 (17)</td>
<td>57.3±1.7 (24)</td>
<td>61.4±1.4 (19)</td>
<td>NS - Group P&lt;0.01 Main Effect Maturation</td>
</tr>
<tr>
<td>Non-Elite 43.1±2.0 (8)</td>
<td>51.0±1.7 (16)</td>
<td>56.9±1.3 (42)</td>
<td>59.5±2.2 (31)</td>
<td>NS - Group P&lt;0.01 Main Effect Maturation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Body Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite 45.7±3.0 (11)</td>
</tr>
<tr>
<td>Non-Elite 43.1±2.0 (8)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tanner Stg 2 Stature (m)</th>
<th>Tanner Stg 3</th>
<th>Tanner Stg 4</th>
<th>Tanner Stg 5</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite 1.58±0.03 (11)</td>
<td>1.62±0.02 (17)</td>
<td>1.66±0.01 (24)</td>
<td>1.65±0.03 (19)</td>
<td>NS Group P&lt;0.01 Main Effect Maturation</td>
</tr>
<tr>
<td>Non-Elite 1.56±0.03 (8)</td>
<td>1.61±0.01 (16)</td>
<td>1.64±0.01 (42)</td>
<td>1.65±0.01 (31)</td>
<td>NS Group P&lt;0.01 Main Effect Maturation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stature (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite 1.58±0.03 (11)</td>
</tr>
<tr>
<td>Non-Elite 1.56±0.03 (8)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tanner Stg 2 Age (y)</th>
<th>Tanner Stg 3</th>
<th>Tanner Stg 4</th>
<th>Tanner Stg 5</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite 13.1±0.2 (11)</td>
<td>14.6±0.2 (17)</td>
<td>15.1±0.2 (24)</td>
<td>15.5±0.3 (19)</td>
<td>NS Group P&lt;0.01 Maturation</td>
</tr>
<tr>
<td>Non-Elite 13.6±0.4 (8)</td>
<td>14.3±0.3 (16)</td>
<td>14.7±0.2 (42)</td>
<td>15.2±0.2 (31)</td>
<td>NS Group P&lt;0.01 Maturation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age (y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite 13.1±0.2 (11)</td>
</tr>
<tr>
<td>Non-Elite 13.6±0.4 (8)</td>
</tr>
</tbody>
</table>
4.3.2. Maturation

Tables 4.4 and 4.5 show the stages of pubic hair (PH) and breast development (GB) attained by the elite and non-elite adolescent female sports performers by age group. When analysed by Tanner’s indices for pubic hair the elite girls were more likely to record a lower stage of development in any age band than the non-elite girls ($P<0.01$). When analysed by Tanner’s indices for breast development there was a tendency for the elite girls to record less pronounced breast development in any age band than the non-elite girls ($P=0.084$).

Table 4.4 Maturation stage by age (y) for elite and non-elite adolescent female sports performers by Tanner stage for pubic hair (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Group</th>
<th>12 years</th>
<th>13 years</th>
<th>14 years</th>
<th>15 years</th>
<th>16 years</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite</td>
<td>2.5±0.3</td>
<td>3.5±0.29</td>
<td>4.0±0.19</td>
<td>4.3±0.2</td>
<td>4.6±0.2</td>
<td>Group P=0.084, P&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>(6)</td>
<td>(13)</td>
<td>(19)</td>
<td>(19)</td>
<td>(12)</td>
<td>Age, Main Effect</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>3.2±0.36</td>
<td>4.0±0.18</td>
<td>4.1±0.16</td>
<td>4.2±0.1</td>
<td>4.4±0.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(10)</td>
<td>(23)</td>
<td>(22)</td>
<td>(31)</td>
<td>(12)</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.5 Maturation stage by age (y) for elite and non-elite adolescent female sports performers by Tanner stage for breast development (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Group</th>
<th>12 years</th>
<th>13 years</th>
<th>14 years</th>
<th>15 years</th>
<th>16 years</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite</td>
<td>1.8±0.3</td>
<td>3.2±0.3</td>
<td>3.8±0.2</td>
<td>3.9±0.2</td>
<td>4.6±0.18</td>
<td>P&lt;0.01, Main Effect</td>
</tr>
<tr>
<td></td>
<td>(6)</td>
<td>(13)</td>
<td>(19)</td>
<td>(19)</td>
<td>(13)</td>
<td>Group</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>3.3±0.37</td>
<td>3.6±0.20</td>
<td>4.1±0.17</td>
<td>4.2±0.2</td>
<td>4.4±0.2</td>
<td>P&lt;0.01, Main Effect</td>
</tr>
<tr>
<td></td>
<td>(9)</td>
<td>(23)</td>
<td>(22)</td>
<td>(31)</td>
<td>(12)</td>
<td>Age</td>
</tr>
</tbody>
</table>

Age x Grp P=0.062
4.3.3 Onset of Menarche
The elite adolescent female sports performers recorded a later onset of menarche than did the non-elite adolescent female sports performers (Table 4.6, P<0.05). The mothers of the elite girls also recorded a later age for onset of menarche than the mothers of the non-elite girls (P<0.05).

Table 4.6 Age of onset of menarche (y) and age of onset of maternal menarche (y) for elite and non-elite adolescent female sports performers (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Group</th>
<th>Onset Menarche (y)</th>
<th>Onset Maternal Menarche (y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite</td>
<td>12.8±0.1 (69)</td>
<td>13.2±0.2 (32)</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>12.4±0.1 (79)</td>
<td>12.5±0.2 (35)</td>
</tr>
<tr>
<td>Significance</td>
<td>P&lt;0.05</td>
<td>P&lt;0.05</td>
</tr>
</tbody>
</table>
4.3.4 Body Composition.
The circumference measurements for the elite and non-elite adolescent female sports performers by age and by maturation stage are shown in Tables 4.7 and 4.8. There were no significant differences between the elite and non-elite girls whether analysed by age or maturation for any measure except for thigh circumference when analysed by maturation stage [Table 4.8] where the elite girls had larger thigh circumferences than the non-elite girls (P<0.05).

Tables 4.9 and 4.10 show the results for the sum of circumferences, the sum seven skinfolds [Triceps, Biceps, Subscapular, Supra-Spinale, Abdominal, Anterior Thigh, Medial Calf], the sum of four skinfolds [Triceps, Biceps, Subscapular, Supra-Spinale], the sum of two skinfolds [Triceps, Subscapular] and the percentage of fat (Lohman, 1992) by age group and maturation stage.

When analysed by age group [Table 4.9] the elite girls had a smaller sum of circumferences (P<0.05), a smaller sum of four skinfolds (P<0.01) and a lower estimated percentage of fat (P<0.01) than the non-elite girls. When analysed by maturation [Table 4.10] there were no significant differences between the elite and non-elite girls for any of the variables.
Table 4.7 Circumference measurements (cm) for elite and non-elite adolescent female sports performers by age (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Group</th>
<th>12.5 years</th>
<th>13.5 years</th>
<th>14.5 years</th>
<th>15.5 years</th>
<th>16.5 years</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Upper Arm</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td>21.2±0.7</td>
<td>24.9±0.9</td>
<td>25.8±0.6</td>
<td>26.0±0.6</td>
<td>26.9±0.9</td>
<td>NS Group</td>
</tr>
<tr>
<td></td>
<td>(6)</td>
<td>(12)</td>
<td>(20)</td>
<td>(18)</td>
<td>(11)</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>23.3±0.8</td>
<td>25.2±0.9</td>
<td>26.3±0.7</td>
<td>25.6±0.4</td>
<td>26.2±1.1</td>
<td>Main Effect</td>
</tr>
<tr>
<td></td>
<td>(11)</td>
<td>(23)</td>
<td>(19)</td>
<td>(27)</td>
<td>(8)</td>
<td>Age</td>
</tr>
<tr>
<td><strong>Waist</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td>62.7±1.3</td>
<td>67.4±1.0</td>
<td>68.8±1.1</td>
<td>69.4±1.2</td>
<td>71.3±1.7</td>
<td>NS Group</td>
</tr>
<tr>
<td></td>
<td>(6)</td>
<td>(12)</td>
<td>(20)</td>
<td>(18)</td>
<td>(11)</td>
<td>P&lt;0.05</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>65.7±1.8</td>
<td>68.4±1.9</td>
<td>70.0±1.4</td>
<td>67.9±0.8</td>
<td>68.2±2.5</td>
<td>Main Effect</td>
</tr>
<tr>
<td></td>
<td>(11)</td>
<td>(23)</td>
<td>(19)</td>
<td>(27)</td>
<td>(8)</td>
<td>Age</td>
</tr>
<tr>
<td><strong>Hip</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td>79.5±1.6</td>
<td>87.0±2.0</td>
<td>90.7±1.9</td>
<td>91.8±2.1</td>
<td>94.7±2.4</td>
<td>NS Group</td>
</tr>
<tr>
<td></td>
<td>(6)</td>
<td>(12)</td>
<td>(20)</td>
<td>(18)</td>
<td>(11)</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>84.0±2.3</td>
<td>90.2±2.2</td>
<td>97.2±4.8</td>
<td>92.5±1.1</td>
<td>92.4±1.4</td>
<td>Main Effect</td>
</tr>
<tr>
<td></td>
<td>(11)</td>
<td>(23)</td>
<td>(19)</td>
<td>(27)</td>
<td>(8)</td>
<td>Age</td>
</tr>
<tr>
<td><strong>Thigh</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td>43.8±1.4</td>
<td>49.3±1.4</td>
<td>51.3±1.0</td>
<td>52.0±1.1</td>
<td>53.7±1.5</td>
<td>NS Group</td>
</tr>
<tr>
<td></td>
<td>(6)</td>
<td>(12)</td>
<td>(20)</td>
<td>(18)</td>
<td>(11)</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>42.3±1.6</td>
<td>48.6±1.1</td>
<td>51.9±1.0</td>
<td>51.9±0.8</td>
<td>53.3±2.0</td>
<td>Main Effect</td>
</tr>
<tr>
<td></td>
<td>(11)</td>
<td>(21)</td>
<td>(16)</td>
<td>(24)</td>
<td>(5)</td>
<td>Age</td>
</tr>
<tr>
<td><strong>Calf</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td>29.4±0.9</td>
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<td>34.3±0.7</td>
<td>35.6±0.6</td>
<td>36.7±1.2</td>
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<tr>
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<td>(20)</td>
<td>(18)</td>
<td>(11)</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>32.4±0.8</td>
<td>33.7±0.7</td>
<td>34.8±0.7</td>
<td>34.4±0.5</td>
<td>35.2±1.1</td>
<td>Main Effect</td>
</tr>
<tr>
<td></td>
<td>(11)</td>
<td>(23)</td>
<td>(19)</td>
<td>(27)</td>
<td>(8)</td>
<td>Age x Group</td>
</tr>
</tbody>
</table>
Chapter 4  Maturation and Body Composition

Table 4.8  Circumference measurements (cm) for elite and non-elite adolescent female sports performers by Tanner stage (PH) (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th></th>
<th>Tanner Stg</th>
<th>Tanner Stg</th>
<th>Tanner Stg</th>
<th>Tanner Stg</th>
<th>Significance</th>
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<tbody>
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<td>2</td>
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<td>4</td>
<td>5</td>
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</tr>
<tr>
<td><strong>Upper Arm</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td>23.0±1.1</td>
<td>25.2±0.9</td>
<td>25.6±0.6</td>
<td>26.8±0.5</td>
<td>NS Group P&lt;0.01</td>
</tr>
<tr>
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<td>(11)</td>
<td>(13)</td>
<td>(22)</td>
<td>(17)</td>
<td>Main Effect Maturation</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>22.1±0.9</td>
<td>23.8±0.6</td>
<td>26.2±0.4</td>
<td>26.2±0.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(6)</td>
<td>(15)</td>
<td>(37)</td>
<td>(27)</td>
<td></td>
</tr>
<tr>
<td><strong>Waist</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td>65.3±1.5</td>
<td>68.2±1.6</td>
<td>68.8±1.2</td>
<td>70.2±1.1</td>
<td>NS Group P&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>(11)</td>
<td>(13)</td>
<td>(22)</td>
<td>(17)</td>
<td>Main Effect Maturation</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>62.2±0.7</td>
<td>65.8±1.1</td>
<td>69.5±1.0</td>
<td>69.8±1.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(6)</td>
<td>(15)</td>
<td>(37)</td>
<td>(27)</td>
<td></td>
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<tr>
<td><strong>Hip</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td>83.2±2.1</td>
<td>88.2±2.2</td>
<td>92.4±1.4</td>
<td>95.8±1.5</td>
<td>NS Group P&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>(11)</td>
<td>(13)</td>
<td>(22)</td>
<td>(17)</td>
<td>Main Effect Maturation</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>80.3±3.4</td>
<td>87.1±1.5</td>
<td>92.6±1.0</td>
<td>96.6±3.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(6)</td>
<td>(15)</td>
<td>(37)</td>
<td>(27)</td>
<td></td>
</tr>
<tr>
<td><strong>Thigh</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td>46.8±1.6</td>
<td>49.9±1.3</td>
<td>52.0±1.0</td>
<td>53.6±1.0</td>
<td>P&lt;0.05 Main Effect Group P&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>(11)</td>
<td>(13)</td>
<td>(22)</td>
<td>(17)</td>
<td>Main Effect Maturation</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>43.4±2.4</td>
<td>48.0±1.1</td>
<td>51.9±0.8</td>
<td>51.1±1.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(6)</td>
<td>(15)</td>
<td>(36)</td>
<td>(17)</td>
<td></td>
</tr>
<tr>
<td><strong>Calf</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td>30.7±1.0</td>
<td>33.0±1.0</td>
<td>34.7±0.7</td>
<td>36.3±0.7</td>
<td>NS Group P&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>(11)</td>
<td>(13)</td>
<td>(22)</td>
<td>(17)</td>
<td>Main Effect Maturation</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>30.9±0.5</td>
<td>32.7±0.4</td>
<td>34.9±0.4</td>
<td>34.9±0.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(6)</td>
<td>(15)</td>
<td>(37)</td>
<td>(27)</td>
<td></td>
</tr>
</tbody>
</table>
Table 4.9  
Sum of circumferences (cm), sum of seven skinfolds (mm) [Triceps, Biceps, Subscapular, Supra-Spinale, Abdominal, Anterior Thigh, Medial Calf], sum of four skinfolds (mm) [Triceps, Biceps, Subscapular, Supra-Spinale], and sum of two skinfolds (mm) [Triceps, Subscapular] for elite and non-elite adolescent female sports performers by age (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Group</th>
<th>12 years</th>
<th>13 years</th>
<th>14 years</th>
<th>15 years</th>
<th>16 years</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite</td>
<td>236.7±5.4</td>
<td>260.7±5.6</td>
<td>270.9±4.7</td>
<td>274.8±4.8</td>
<td>283.3±7.0</td>
<td>P&lt;0.05 Main Effect Group</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>250.6±7.0</td>
<td>262.0±4.8</td>
<td>276.2±7.5</td>
<td>266.6±3.4</td>
<td>255.3±12.7</td>
<td>P&lt;0.05 Main Effect Age</td>
</tr>
</tbody>
</table>

Sum of 7 Skinfolds (mm)

<table>
<thead>
<tr>
<th>Group</th>
<th>12 years</th>
<th>13 years</th>
<th>14 years</th>
<th>15 years</th>
<th>16 years</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite</td>
<td>58.1±5.3</td>
<td>96.4±8.9</td>
<td>96.3±8.0</td>
<td>93.7±7.0</td>
<td>109.4±10.3</td>
<td>NS Group</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>87.8±7.9</td>
<td>109.2±10.0</td>
<td>110.0±6.3</td>
<td>103.5±5.4</td>
<td>104.4±12.9</td>
<td>P&lt;0.05 Age x Group</td>
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</table>

Sum of 4 Skinfolds (mm)

<table>
<thead>
<tr>
<th>Group</th>
<th>12 years</th>
<th>13 years</th>
<th>14 years</th>
<th>15 years</th>
<th>16 years</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite</td>
<td>24.2±2.5</td>
<td>40.6±4.5</td>
<td>45.3±5.2</td>
<td>45.9±2.8</td>
<td>52.6±4.8</td>
<td>P&lt;0.01 Main Effect Group</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>40.8±4.2</td>
<td>51.8±5.3</td>
<td>53.2±3.4</td>
<td>52.1±3.2</td>
<td>53.1±5.5</td>
<td>P&lt;0.05 Main Effect Age</td>
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</tbody>
</table>

Sum of 2 Skinfolds (mm)

<table>
<thead>
<tr>
<th>Group</th>
<th>12 years</th>
<th>13 years</th>
<th>14 years</th>
<th>15 years</th>
<th>16 years</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite</td>
<td>13.8±1.1</td>
<td>22.5±2.3</td>
<td>25.3±2.8</td>
<td>24.4±1.1</td>
<td>29.3±3.0</td>
<td>NS Group</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>20.5±1.8</td>
<td>26.2±2.7</td>
<td>27.9±1.6</td>
<td>30.3±1.6</td>
<td>29.3±2.5</td>
<td>P&lt;0.01 Main Effect Age</td>
</tr>
</tbody>
</table>

Estimated Percentage Fat – Lohman (1992)

<table>
<thead>
<tr>
<th>Group</th>
<th>12 years</th>
<th>13 years</th>
<th>14 years</th>
<th>15 years</th>
<th>16 years</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite</td>
<td>18.5±1.0</td>
<td>25.3±1.4</td>
<td>26.0±1.0</td>
<td>27.1±1.0</td>
<td>29.3±1.6</td>
<td>P&lt;0.01 Main Effect Group</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>24.0±1.5</td>
<td>26.5±1.3</td>
<td>29.1±1.0</td>
<td>30.3±1.0</td>
<td>30.0±1.4</td>
<td>P&lt;0.01 Main Effect Age</td>
</tr>
</tbody>
</table>
### Table 4.10  
Sum of circumferences (cm), sum of seven skinfolds (mm) [Triceps, Biceps, Subscapular, Supra-Spinale, Abdominal, Anterior Thigh, Medial Calf], sum of four skinfolds (mm) [Triceps, Biceps, Subscapular, Supra-Spinale], and sum of two skinfolds (mm) [Triceps, Subscapular] for elite and non-elite adolescent female sports performers by Tanner stage (PH) (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Tanner Stg</th>
<th>Sum of Circumferences (cm)</th>
<th>Non-Elite (6) (15) (37) (27)</th>
<th>Maturation</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Elite 249.1±7.0 (11)</td>
<td>Non-Elite 265.5±24.9 (6)</td>
<td>Main Effect</td>
<td>*P&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>264.5±6.6 (13)</td>
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</tr>
<tr>
<td></td>
<td>273.6±4.6 (22)</td>
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<tr>
<td></td>
<td>282.7±4.2 (17)</td>
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</tr>
<tr>
<td>3</td>
<td>Elite 264.5±6.6 (13)</td>
<td>Non-Elite 257.4±4.0 (15)</td>
<td>Main Effect</td>
<td>*P&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>273.8±3.6 (37)</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>259.7±5.6 (27)</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>4</td>
<td>Elite 81.4±11.4 (11)</td>
<td>Non-Elite 81.0±13.4 (6)</td>
<td>Main Effect</td>
<td>*P&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>84.5±6.6 (13)</td>
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</tr>
<tr>
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<td>100.3±7.9 (22)</td>
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<tr>
<td></td>
<td>105.8±6.6 (17)</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>5</td>
<td>Elite 81.0±13.4 (6)</td>
<td>Non-Elite 84.4±5.6 (15)</td>
<td>Main Effect</td>
<td>*P&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>114.8±5.3 (37)</td>
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</tr>
<tr>
<td></td>
<td>110.1±7.2 (27)</td>
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</table>

<table>
<thead>
<tr>
<th>Estimated Percentage Fat (Lohman, 1992)</th>
<th>Elite</th>
<th>Non-Elite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>22.1±1.8 (11)</td>
<td>22.8±2.2 (6)</td>
</tr>
<tr>
<td></td>
<td>25.1±1.7 (13)</td>
<td>25.5±1.2 (15)</td>
</tr>
<tr>
<td></td>
<td>26.7±0.9 (22)</td>
<td>29.5±0.8 (37)</td>
</tr>
<tr>
<td></td>
<td>27.8±1.0 (17)</td>
<td>29.8±0.9 (27)</td>
</tr>
<tr>
<td></td>
<td>Group - NS</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Main Effect</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maturation</td>
</tr>
</tbody>
</table>
4.3.5 Elite Athlete Subsets – Age and physical characteristics

Table 4.11 shows the results of analysis of the differences between the elite athlete subsets as defined in the general methods, section 3.7. Within the elite subsets the 'individual other' athletes had an earlier onset of menarche than the 'team players', the 'individual endurance' and the 'individual games' athletes (P<0.05). There was a tendency for the 'individual other' athletes to be shorter than the 'team players', the 'individual endurance' and the 'individual games' athletes (P=0.08). There was a difference in body mass between the groups with the 'team players' being the heaviest and the 'individual endurance' being the lightest (P<0.05, main effect group). There was a difference in the age at menarche with 'individual other' athletes being the earliest at 12.2 y and 'individual games players' the latest at 13.3 y (P<0.05, main effect group).
Table 4.11 Age (y), maturation status (Tanner (1962) Indices), stature (m), body mass (kg), age of onset of menarche (y), and age of onset of maternal menarche (y) for elite adolescent female sports performers in the following groups team players, elite individual endurance athletes, elite individual team players and elite individual athletes from other disciplines (mean ± SE) by Group. Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Team Players</th>
<th>Individual Endurance</th>
<th>Individual Games</th>
<th>Individual Other</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>15.26±0.21(36)</td>
<td>14.67±0.21(16)</td>
<td>14.94±0.28(15)</td>
<td>14.56±0.31(20)</td>
<td>NS</td>
</tr>
<tr>
<td>Maturity (PH)</td>
<td>3.6 ± 0.2 (27)</td>
<td>3.8 ± 0.2 (16)</td>
<td>4.0 ± 0.3 (10)</td>
<td>3.6 ± 0.3 (19)</td>
<td>NS</td>
</tr>
<tr>
<td>Maturity (GB)</td>
<td>3.9 ± 0.2 (27)</td>
<td>3.6 ± 0.2 (16)</td>
<td>4.5 ± 0.2 (10)</td>
<td>3.8 ± 0.3 (19)</td>
<td>NS</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.66 ± 0.01(36)</td>
<td>1.66 ± 0.01(16)</td>
<td>1.65 ± 0.02(15)</td>
<td>1.60 ± 0.03(20)</td>
<td>P&lt;0.05* Main Effect Group</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>59.7 ± 1.8 (36)</td>
<td>50.7 ± 1.4 (16)</td>
<td>55.4 ± 1.5 (15)</td>
<td>55.4 ± 2.4 (20)</td>
<td>P&lt;0.05* Main Effect Group</td>
</tr>
<tr>
<td>Age of onset of Menarche (y)</td>
<td>12.8 ± 0.2 (30)</td>
<td>13.2 ± 0.2 (12)</td>
<td>13.3 ± 0.3 (13)</td>
<td>12.2 ± 0.3 (15)</td>
<td>P&lt;0.05 Main Effect Group</td>
</tr>
<tr>
<td>Maternal age of onset of Menarche (y)</td>
<td>13.4±0.5 (8)</td>
<td>13.3 ± 0.3 (11)</td>
<td>12.8 ± 0.9 (3)</td>
<td>12.9 ± 0.41 (11)</td>
<td>NS</td>
</tr>
</tbody>
</table>

Post Hoc: * Team v Individual Endurance P<0.05
4.3.6 Elite Athlete Subsets – Body Composition

Tables 4.12 and 4.13 show the results of the analysis of the body composition measures for the elite athlete subsets.

Table 4.12 shows the skinfold measures for the elite athlete subsets. Within the elite subsets the ‘individual endurance’ athletes had lower supra-spinale and abdominal skinfold measures than the ‘individual other’, the ‘individual game players’ and the ‘team’ athletes (P<0.05). There was a tendency for the ‘individual endurance’ athletes to have a lower sum of four skinfolds than the ‘individual other’, the ‘individual game players’ and the ‘team’ athletes (P=0.06). There was a tendency for the ‘individual endurance’ athletes to have a lower estimated body fat percentage (Lohman, 1992) than the ‘individual other’, the ‘individual game players’ and the ‘team’ elite athletes (P=0.076).

Table 4.13 shows the circumference measures for the elite athlete subsets. Within the elite subsets the ‘individual endurance’ athletes had lower waist circumference than the ‘individual other’, the ‘individual game players’ and the ‘team’ athletes (P<0.05), whilst the ‘individual games’ players had lower hip circumferences than the ‘individual other’, the ‘individual endurance’ and the ‘team’ athletes (P<0.05) and had a lower sum of seven circumferences than the ‘individual other’, the ‘individual endurance’ and the ‘team’ athletes (P<0.01). There was a tendency for the individual endurance athletes to have lower thigh circumferences than the ‘individual other’, the ‘individual game players’ and the ‘team’ athletes (P=0.064).
Table 4.12 Body Composition – Skinfold measures for elite adolescent female sports performers in the following groups: team players, elite individual endurance athletes, elite individual team players and elite individual athletes from other disciplines (mean ± SE) by Group. Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Team Players</th>
<th>Individual Endurance</th>
<th>Individual Games</th>
<th>Individual Other</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triceps Skinfold (mm)</td>
<td>14.3 ± 0.9 (24)</td>
<td>11.7 ± 0.7 (15)</td>
<td>14.8 ± 1.1 (9)</td>
<td>14.3 ± 1.0 (20)</td>
<td>NS</td>
</tr>
<tr>
<td>Biceps Skinfold (mm)</td>
<td>8.8 ± 1.3 (24)</td>
<td>6.9 ± 0.53 (15)</td>
<td>8.5 ± 1.0 (9)</td>
<td>7.7 ± 0.6 (20)</td>
<td>NS</td>
</tr>
<tr>
<td>Subscapular Skinfold (mm)</td>
<td>12.1 ± 2.0 (24)</td>
<td>7.5 ± 0.5 (15)</td>
<td>11.8 ± 2.5 (9)</td>
<td>9.3 ± 0.8 (20)</td>
<td>NS</td>
</tr>
<tr>
<td>Supra-Spinale Skinfold (mm)</td>
<td>13.5 ± 1.4 (24)</td>
<td>8.3 ± 1.0 (15)</td>
<td>15.1 ± 1.9 (9)</td>
<td>10.1 ± 1.6 (20)</td>
<td>P&lt;0.05 Main Effect Group</td>
</tr>
<tr>
<td>Abdominal Skinfold (mm)</td>
<td>16.3 ± 1.5 (24)</td>
<td>10.9 ± 0.8 (15)</td>
<td>13.4 ± 1.3 (9)</td>
<td>15.2 ± 1.4 (20)</td>
<td>P&lt;0.05 Main Effect Group</td>
</tr>
<tr>
<td>Anterior Thigh Skinfold (mm)</td>
<td>22.3 ± 1.7 (24)</td>
<td>18.7 ± 1.5 (15)</td>
<td>20.8 ± 1.5 (9)</td>
<td>23.0 ± 1.2 (20)</td>
<td>NS</td>
</tr>
<tr>
<td>Medial Calf Skinfold (mm)</td>
<td>15.8 ± 1.7 (23)</td>
<td>14.2 ± 1.5 (15)</td>
<td>14.8 ± 1.0 (10)</td>
<td>17.1 ± 1.2 (20)</td>
<td>NS</td>
</tr>
<tr>
<td>Sum of 2 Skinfolds (mm): Triceps &amp; Subscapular</td>
<td>26.4 ± 2.6 (24)</td>
<td>19.2 ± 1.1 (15)</td>
<td>26.6 ± 3.0 (9)</td>
<td>23.6 ± 1.7 (20)</td>
<td>NS</td>
</tr>
<tr>
<td>Sum of 4 Skinfolds (mm): Triceps, Biceps, Subscapular &amp; Supra-Spinale</td>
<td>48.7 ± 4.8 (24)</td>
<td>34.4 ± 2.3 (15)</td>
<td>50.2 ± 4.3 (9)</td>
<td>41.5 ± 3.4 (20)</td>
<td>P=0.060 Main Effect Group</td>
</tr>
<tr>
<td>Sum of 7 Skinfolds (mm)</td>
<td>102.4 ±8.5 (24)</td>
<td>78.1 ± 4.5 (15)</td>
<td>90.8 ±10.1 (10)</td>
<td>96.8 ±6.6 (20)</td>
<td>NS</td>
</tr>
<tr>
<td>Estimated Percentage of Fat (Lohman, 1992)</td>
<td>26.7 ± 1.1 (24)</td>
<td>23.7 ± 0.9 (16)</td>
<td>28.0 ± 1.4 (9)</td>
<td>26.2 ± 1.2 (20)</td>
<td>P=0.076 Main Effect Group</td>
</tr>
</tbody>
</table>
Table 4.13  Body Composition – Circumference measures for elite adolescent female sports performers in the following groups: team players, elite individual endurance athletes, elite individual team players and elite individual athletes from other disciplines (mean ± SE) by Group. Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Team Players</th>
<th>Individual Endurance</th>
<th>Individual Games</th>
<th>Individual Other</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Arm Girth (cm)</td>
<td>26.3 ± 0.8</td>
<td>23.9 ± 0.6</td>
<td>25.2 ± 0.5</td>
<td>25.5 ± 0.7</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>(24)</td>
<td>(15)</td>
<td>(9)</td>
<td>(20)</td>
<td></td>
</tr>
<tr>
<td>Waist Girth (cm)</td>
<td>70.0 ± 1.2</td>
<td>65.3 ± 0.9</td>
<td>67.8 ± 1.0</td>
<td>69.3 ± 1.1</td>
<td>P&lt;0.05*</td>
</tr>
<tr>
<td></td>
<td>(24)</td>
<td>(15)</td>
<td>(9)</td>
<td>(20)</td>
<td>Main Effect Group</td>
</tr>
<tr>
<td>Hip Girth (cm)</td>
<td>97.8 ± 1.7</td>
<td>87.1 ± 1.3</td>
<td>84.4 ± 4.1</td>
<td>90.8 ± 2.0</td>
<td>P&lt;0.05**</td>
</tr>
<tr>
<td></td>
<td>(24)</td>
<td>(15)</td>
<td>(9)</td>
<td>(20)</td>
<td>Main Effect Group</td>
</tr>
<tr>
<td>Thigh Girth (cm)</td>
<td>51.9 ± 1.3</td>
<td>48.1 ± 0.8</td>
<td>49.1 ± 1.5</td>
<td>52.2 ± 1.1</td>
<td>P=0.064</td>
</tr>
<tr>
<td></td>
<td>(24)</td>
<td>(15)</td>
<td>(9)</td>
<td>(20)</td>
<td>Main Effect Group</td>
</tr>
<tr>
<td>Calf Girth (cm)</td>
<td>34.2 ± 0.9</td>
<td>32.5 ± 0.5</td>
<td>35.0 ± 0.1</td>
<td>34.2 ± 0.4</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>(24)</td>
<td>(15)</td>
<td>(9)</td>
<td>(20)</td>
<td></td>
</tr>
<tr>
<td>Sum of all Circumferences (cm)</td>
<td>275.5±5.6</td>
<td>256.1±3.7</td>
<td>196.1±34.4</td>
<td>271.1±5.4</td>
<td>P&lt;0.01***</td>
</tr>
<tr>
<td></td>
<td>(24)</td>
<td>(15)</td>
<td>(9)</td>
<td>(20)</td>
<td>Main Effect Group</td>
</tr>
</tbody>
</table>

Post Hoc

* Team v Individual Endurance P<0.05,
  Individual Endurance v Individual Other P=0.088 (Tukey P=0.068)

** Team v Individual Games P=0.085 (Tukey P=0.066)

*** Team v Individual Games P<0.01
  Individual Endurance v Individual Games P<0.05
  Individual Games v Individual Other P<0.01
4.5 Discussion

The main findings in this study were that the elite athletes recorded a later mean age of menarche than the non-elite athletes (P<0.05) and that the mothers of the elite athletes also recorded a later mean age of menarche than the mothers of the non-elite athletes (P<0.05). The elite athletes were more likely than the non-elite girls to record a lower (less advanced) stage of maturational development as defined by Tanner's indices for pubic hair (P<0.01) in all age groups. When analysed by Tanner's indices for breast development there was a tendency for the elite athletes to record less pronounced breast development than the non-elite athletes in all age groups (P=0.084). The elite athletes had larger thigh circumferences than the non-elite athletes when analysed by maturation stage (P<0.05), though not when analysed by age group. The elite girls also had a lower sum of circumferences (P<0.05), a smaller sum of 4 skinfolds (P<0.01) and a lower estimated percentage of body fat (P<0.01) than the non-elite girls when analysed by age group, but not by maturation stage. There were no observed differences in stature or body mass between the elite and non-elite female adolescent athletes.

The elite athletes in the present study (Running, Swimming, Biathlon, Triathlon, Badminton, Squash, Tennis, Athletics-track, Athletics-field, Golf, Gymnastics, Karate, Sculling, Tae-Kwando, Wind-Surfing, Fencing, Rugby, Volleyball, Water-Polo, Basketball, Cricket, Hockey, Football, Lacrosse and Netball) had a later onset of menarche than the non-elite athletes. A later onset of menarche in elite athletes (Swimming, Track & Field, Basketball, Volleyball, Rowing, Canoeing, Gymnastics and Figure Skating), when compared to non-elite athletes has been previously reported (Malina et al., 1979; Malina, 1983; Baxter-Jones et al., 1994; Beunen and Malina, 1996) and, in general it is agreed that the degree of delay is related to the level at which the athlete competes. However, whether this is due to the amount of training that an athlete does or is due to other factors (e.g. genetic variation) is open to debate. Claessens et al (2003), found that amongst a large sample (n=212) of international junior rowers there was no direct evidence to support the theory that "intensive rowing training has a negative influence on the maturation status of junior female athletes". The same authors were also unable to find any relationships between age at menarche and physical and body composition characteristics and found that there were no differences in the mean
The median age of menarche in the normal healthy British population (girls born between 1982 and 1986) is currently around 13 years of age (Whincup et al., 2001). In a study of 1166 secondary school girls aged 12 - 16 in schools in 10 British towns, Whincup et al (2001) found only small geographical, social and ethnic variations suggesting that non-response bias in menarcheal age was limited. When compared with data for British girls (n=7000) born between 1950 and 1965 (Tanner, 1973) the current
data suggests that the median menarcheal age reported is close to or slightly below the earlier findings.

Thus the findings in the present study support and strengthen the suggestion that the elite female adolescent athlete is a late maturer, but highlights that there are sport specific variations with 'individual games players' and 'individual endurance' athletes likely to be the least mature and 'team games players' the most mature, but still less mature than inactive individuals.

In the present study the mean age of menarche for the mothers of the elite athletes was also later than the mean age for the mothers of the non-elite athletes. At present there is very little in the literature that confirms an association between the age of onset of menarche in mothers and daughters; however, Baxter-Jones et al. (1994) looked at age of menarche in 201 athletes and their mothers and found that mothers’ and daughters’ menarcheal ages were positively correlated in the three sports examined, swimming, gymnastics and tennis (Baxter-Jones et al., 1994). Malina et al. (1994), in a study of university athletes (n=109), their mothers (n=109) and sisters (n=77), found that whilst the athletes in the study reported retrospectively that they had a later age of onset of menarche, so did their mothers and sisters, suggesting that later onset of menarche in the athlete was likely to be familial (Malina et al., 1994). Brooks-Gunn and Warren (1988) however, in a comparison study of white adolescent girls (n=350) attending either national dance company schools (n=63) or private day schools (n=287), asked the participants and their mothers to complete a questionnaire about their age of menarche. The adolescent girls were weighed and measured. This study also investigated the leanness and dieting behaviour of both groups of girls, as preselection for particular physiques and somatotypes may favour a late maturing girl in many forms of sport and physical activity. The study looked at ballet dancers, who when chosen during (competitive) entry to ballet school tend to be leaner than average (Brooks-Gunn and Warren, 1988). It is known that lean girls are more likely to have a later menarche (Tanner, 1962), and this was supported in the study by the lean ballet dancers having a later menarche than the comparison group of adolescents, which was not supported by their mothers’ menarcheal age; whilst, on the other hand, maternal menarcheal age was
the best predictor of menarcheal age in the comparison sample (Brooks-Gunn and Warren, 1988).

Thus the findings of the present study add weight to the suggestion that the mean age of menarche is determined by genetic factors rather than as an effect of training.

The circumference measures of the limbs and trunk of the athletes in the current study showed no differences between elite and non-elite female adolescent athletes apart from the thigh circumference measure of the elite girls which was larger (P<0.05) than that of the non-elite girls when analysed by maturation stage. The elite girls however, had a lower (P<0.05) sum of all circumferences when analysed by age group. The elite girls were less fat (P<0.01), when adiposity is measured by skinfold thickness, than the non-elite girls when analysed by age group. When adiposity was measured using Lohman’s equation (Lohman, 1992), the elite girls had lower (P<0.01) fat percentages than the non-elite girls. Limb circumference is a good indicator of relative muscularity as the circumference of a limb includes bone, surrounded by muscle tissue, which is ringed by a layer of subcutaneous fat. The elite girls in this study were thinner and had less body fat. The larger thigh circumference indicates greater muscle mass in the legs of the elite girls which would be a logical result of the level of training that is required for elite status in sport.

Thus, the findings of the present study cannot rule out the possibility that leanness may also play a role as the elite girls were leaner as were the ‘individual endurance’ athletes and the ‘individual games players’ who were also the least mature, than the non-elite athletes.

4.6 Conclusion

In conclusion, the elite girls in this study were significantly more likely to have a later onset of menarche, to be less fat and have more muscular legs, with smaller circumferences overall than their non-elite colleagues. Surprisingly they were not different in height and body mass to the non-elite girls; this may be due to the wide range of sports and types of sport that the elite cohort participated in. The mother’s of
the elite girls were more likely to have a later onset of menarche than the mothers of the non-elite girls, suggesting that the age of menarche is probably determined by genetic factors.
CHAPTER 5

Peak oxygen uptake and the submaximal responses to treadmill running in elite and non-elite female adolescent athletes.

5.1 Introduction

Maximum oxygen uptake or $\dot{V}O_2$ max, is the maximum amount of oxygen that the body can consume during work for the aerobic production of ATP (Wilmore and Costill, 1999; Armstrong and Welsman, 2000b). Traditionally it has been assumed that oxygen consumption rises along with an increase in exercise intensity until the point is reached where there is no further rise in oxygen consumption and oxygen consumption levels off to a plateau. (Armstrong and Welsman, 2000b). The plateau in oxygen consumption is rarely seen particularly with children and adolescents. Varying reasons have been postulated for the failure to reach a plateau including, lack of motivation and low ‘anaerobic capacity’ being two commonly cited (Krahenbuhl et al., 1985). As the term $\dot{V}O_2$ max implies a plateau, it has become the norm in paediatric exercise science to define the highest oxygen consumption seen during an exercise test to exhaustion as $\dot{V}O_2$ peak or peak $\dot{V}O_2$.

The literature comparing the $\dot{V}O_2$ peak of elite adolescent athletes and non-elite adolescent athletes is sparse and primarily investigates males (Sjödin and Svedenhag, 1992; Kobayashi et al., 1978; Murase et al., 1981; Paterson et al., 1987). As is often the case, the definition of athlete varies from study to study with the best overall description of the cohorts being ‘trained’. Two studies included adolescent female athletes as well as adolescent male athletes (Van Huss et al., 1988; Eisenmann et al., 2001) but again the definition of elite is unclear. Thus there is a paucity of research regarding the $\dot{V}O_2$ peak of elite female adolescent athletes compared to non-elite female adolescent athletes. The purpose of the current study was to examine the $\dot{V}O_2$ peak of the elite female adolescent athletes and their non-elite colleagues and to test the hypothesis that the elite females will have a higher $\dot{V}O_2$ peak than the non-elite females.
Running economy is the rate of oxygen consumption at a given treadmill speed or incline, or the amount of oxygen required by the body to maintain a constant velocity (Saunders et al., 2004; Pate and Ward, 1996; Jones and Carter, 2000b). Running economy is a measurement of the metabolic cost of running at a given velocity, therefore, the less energy (and as a consequence, the less oxygen) it takes to maintain the velocity the more economical the athlete is deemed to be (Foster and Lucia, 2007; Frederick, 1992).

It has been demonstrated that young athletes are less economical than adults at a given treadmill speed and/or incline (Allor et al., 2000; Turley and Wilmore, 1997). As running economy develops with age it appears to be related to changes in body size (body mass and Fat Free Mass [FFM]) rather than to changes that are related to sexual maturation (Armstrong et al., 1999). Changes in VO$_2$ peak appear to be more closely related to FFM than to total body mass (Malina et al., 2004b). Traditionally VO$_2$ peak is expressed as a ratio standard (ml.kg$^{-1}$.min$^{-1}$), but as the relationship between body mass and VO$_2$ peak is not linear it is difficult to interpret the changes that occur due to growth and maturation.

Welsman and Armstrong (2000a) controlled for body mass using allometry in a longitudinal study (annual measures over three consecutive years) looking at the development of submaximal oxygen uptake in boys (118) and girls (118), aged 11.2 ± 0.4 y (mean ± sd) at the onset of the study. They found that the submaximal VO$_2$ responses were explained by changes in body mass and skinfold thicknesses and that maturity did not have an effect in either boys or girls. When differences in body mass and skinfolds were controlled for there was a difference between the sexes in submaximal VO$_2$, with the girls consuming significantly less VO$_2$ than the boys when running at 8 km.h$^{-1}$. They found that the girls became more economical than the boys as they got older.

Rowland (1998) came to the conclusion that in activities that are load bearing, such as distance running, ratio scaling was a more appropriate method to use than allometric
scaling when relating variables such as \( \text{VO}_2 \) peak to performance. This is because as growth occurs the total body mass shifted and supported is still relative to the total work done by the individual, and, indeed that performance in events such as a distance run is dictated by the actual mass that has to be transported (Rowland, 1998). This method does not account for FFM, but it is still a convenient and popular method of normalising results across a population in cross sectional studies. Allometry comes into its own when dealing with the complexities of longitudinal studies. Using ratio scaling Sjödin and Svedenhag (1992) examined oxygen uptake longitudinally during running in elite versus non-elite boys and found that the maximal oxygen uptake \( \text{VO}_2 \text{max} \) (ml.kg\(^{-1}\)min\(^{-1}\)) decreased with growth in the untrained group but remained almost constant in the trained group. The oxygen cost of running at 15 km.h\(^{-1}\) (\( \text{VO}_2 \text{15} \) ml.kg\(^{-1}\)min\(^{-1}\)) was persistently lower in the trained group but decreased similarly with age in both groups. The development of \( \text{VO}_2 \text{max} \) and \( \text{VO}_2 \text{15} \) (l.min\(^{-1}\)) was related to each individual’s increase in body mass so that power functions were obtained. The mean body mass scaling factor was 0.78 and 1.01 for \( \text{VO}_2 \text{max} \) and 0.75 and 0.75 for \( \text{VO}_2 \text{15} \) in trained and untrained groups respectively. Therefore, when expressed as ml.kg\(^{-0.75}\)min\(^{-1}\), \( \text{VO}_2 \text{15} \) was unchanged in both groups and \( \text{VO}_2 \text{max} \) increased only in the trained group. Thus, \( \text{VO}_2 \) determined during treadmill running may be better related to kg\(^{0.75}\) than to the normally used kg\(^1\) (Sjödin and Svedenhag, 1992). On the other hand, however, Nevill et al, (2004) investigated whether or not the ratio standard was an appropriate method of normalising \( \text{VO}_2 \text{max} \) to predict the speed of a 1-mile run in a group (n=36) of 12 year old boys. A power function model and log-linear regression were used to find the best predictor of 1-mile run speed; the model suggests that the best predictor of 1-mile run speed is almost exactly the same as the traditional ratio scaling standard as recorded using the units (ml.kg\(^{-1}\).min\(^{-1}\)). An earlier study by Nevill et al (1992) found that the traditional ratio standards (ml.kg\(^{-1}\).min\(^{-1}\)) and (W.kg\(^{-1}\)) best described a wide range of subjects according to their performance capacities or ability to run – which are highly dependent on body size.

Lactate is one of the by products of glycolysis, both produced by and used by the muscles. As exercise intensity increases, the amount of carbohydrate used increases and the amount of lactate produced also increases (Noakes, 2001). The terms ‘anaerobic
threshold', 'lactate threshold' and 'lactate turnpoint' are terms commonly used to describe the point at which, during exercise, the blood lactate levels start to rise visibly (McArdle et al., 2001; Armstrong and Welsman, 2007). Noakes (2001) states that none of these terms are justifiable as recent research has shown that there is no clearly defined abrupt threshold response during exercise of progressively increasing intensity. Rather that blood lactate concentrations begin to rise, albeit very slowly, as soon as progressive exercise starts (Noakes, 2001). Once intense exercise begins then the rise in blood lactate concentration becomes apparent (Noakes, 2001). The concentration of lactate in the blood depends on the rate of diffusion from the muscle fibre into the blood stream and the rate of clearance from the blood (Shephard, 1992).

Young athletes' lactate responses to endurance exercise are characteristically lower than the 4mmol.l\(^{-1}\) blood lactate concentration extensively used to monitor and prescribe training in adults. Williams and Armstrong (1990) studied both boys and girls, aged 11 – 13 years old, and found that the exercise intensity required to produce a blood lactate concentration of 4 mmol.l\(^{-1}\) was reached at around 91% of their peak oxygen uptake values in both sexes. Later, Tolfrey and Armstrong (1995) found that prepubertal and teenage boys were able to exercise at high intensities without accumulating high concentrations of blood lactate. They found that a level of 2.5 mmol.l\(^{-1}\) blood lactate concentration was indicative of similar percentages of \(\text{VO}_2\) peak in prepubertal boys, adolescents and men.

In summary, while there are some studies describing running economy and one study examining running economy in elite versus non-elite male adolescents there are no studies comparing running economy and the blood lactate response to submaximal exercise in elite and non-elite adolescent females and no studies examining different sporting groups. Thus the purpose of the present study was to examine peak \(\text{VO}_2\), running economy and the blood lactate response to submaximal running in elite and non-elite adolescent female athletes and in the sporting groups of 'Elite Team Players'; 'Elite Individual Endurance'; 'Elite Individual Games Players'; and 'Elite Others'.
5.2 Methods

5.2.1 Participants

Eighty six elite and 100 non-elite adolescent females aged between 12 and 17 years (mean ± se); elite 14.9 y ± 0.1; non-elite 14.7 y ± 0.1, (Table 5.1) volunteered to take part in the study. A more detailed description can be seen in Chapter 3, General Methods.

Table 5.1 Mean age (y) for elite and non-elite adolescent female sports performers by age group. Group numbers are indicated by the figure in the brackets (mean ± SE).

<table>
<thead>
<tr>
<th>Group</th>
<th>12 years</th>
<th>13 years</th>
<th>14 years</th>
<th>15 years</th>
<th>16 years</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite</td>
<td>12.7±0.1</td>
<td>13.4±0.5</td>
<td>14.5±0.4</td>
<td>15.5±0.4</td>
<td>16.4±0.5</td>
<td>NS Group</td>
</tr>
<tr>
<td></td>
<td>(6)</td>
<td>(15)</td>
<td>(21)</td>
<td>(23)</td>
<td>(21)</td>
<td>P&lt;0.01 Main Effect Age</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>12.8±0.7</td>
<td>13.6±0.5</td>
<td>14.5±0.4</td>
<td>15.4±0.4</td>
<td>16.5±0.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(11)</td>
<td>(23)</td>
<td>(22)</td>
<td>(31)</td>
<td>(13)</td>
<td></td>
</tr>
</tbody>
</table>

5.2.2 Physical Characteristics

Stature was measured to the nearest 0.1 cm and body mass to the nearest 0.1 kg. Skinfold thickness for the determination of body fatness was measured at the following sites using a Harpenden calliper: tricep, bicep, subscapular and supraspinale (Norton et al., 1996; Marfell-Jones et al., 2006), the mean value of three measurements at each site was then summed to give the skinfold measurement as the sum of four skinfolds. For a more detailed account of the method of skinfold measurement please refer to section Chapter 3, General Methods. Age was calculated from the date of birth and the date of the test. All participants were asked to perform a self-assessment of maturity by assessing their secondary sexual characteristics according to Tanner’s (1962) indices of secondary sex characteristics. A more detailed account of the procedure can be seen in Chapter 3, General Methods.
5.2.3 Treadmill Running Tests

The participants commenced the submaximal incremental treadmill test at least 60 minutes prior to commencing the test to determine peak oxygen uptake (\( \dot{VO}_2 \) peak). Before performing each test each participant was familiarised with treadmill walking and running (for a more detailed account please see Chapter 3, General Methods) and was instructed in the safety procedures. Prior to starting the submaximal incremental treadmill test a resting finger-prick capillary blood sample was collected for the determination of resting blood lactate concentration by a fluorometric method (Maughan, 1982). For a more detailed account of this procedure please see Chapter 3, General Methods.

5.2.4 Determination of peak oxygen uptake (\( \dot{VO}_2 \) peak)

The peak oxygen uptake test is described in detail in Chapter 3, General Methods. The participants were required to perform a continuous incremental uphill treadmill run to voluntary exhaustion. \( \dot{VO}_2 \) peak was regarded as that achieved during the final minute of the test and was deemed to have occurred when at least two of the following criteria were achieved 1) peak recorded heart rate greater than 95% of age predicted maximum (220 – age); 2) a peak respiratory exchange ratio (RER) value greater than unity; 3) subjective signs of fatigue (e.g. an inability to keep pace with the treadmill, facial flushing, hyperpnoea, dyspnoea, and unsteady gait).

5.2.5 Submaximal incremental treadmill test

The test procedure for the submaximal incremental treadmill test is outlined in Chapter 3, General Methods. In brief, subjects ran for 4 minutes at each of 3 or 4 increasing speeds starting at 8 km.h\(^{-1}\) and increasing by 1 km.h\(^{-1}\) every 4 min. There was a 30 s break between each stage to facilitate blood sampling.

5.2.6 Blood lactate sampling and analysis

The blood sampling collection, treatment and storage procedures used in this study are described in detail in Chapter 3, General Methods. In brief, duplicate 20\( \mu \)l capillary
blood samples were collected prior to the start of the submaximal, incremental treadmill running test and again at the end of each stage of the submaximal running test, centrifuged, frozen and later analysed for lactate using the fluorometric method (Maughan 1982: see appendix M)

5.2.7 Statistical analysis
Descriptive statistics for physical characteristics were calculated for elite and non-elite groups by age and maturational stage. Two-way (age x group) and (maturity x group) analysis of variance (ANOVA) were used to determine absolute differences between absolute \( \dot{V}O_2 \) peak and relative \( \dot{V}O_2 \) peak (expressed per kg\(^{1.0}\) body mass).

The statistics used to examine any differences between the groups for the incremental submaximal treadmill running test were a mixed three-factor factorial analysis (ANOVA) with one within subject factor. For example the 3 factors were age, group and treadmill speed (age x group x treadmill speed); maturity, group, and treadmill speed (maturity x group x treadmill speed); for each of the variables studied; i.e. oxygen uptake, blood lactate concentration, RPE, R value, running economy, heart rate etc. Results are expressed as mean ± standard error (SE).
Chapter 5  
Treadmill Running

5.3 Results

5.3.1 Physical characteristics
The physical characteristics of the elite and non-elite adolescent female sports performers aged 12 - 17 years who participated in the study are presented in tables 4.1, 4.2, 4.3, 4.4 in Chapter 4 of this thesis.

5.3.2 Peak Oxygen Uptake

The elite athletes had a higher peak oxygen uptake (l.min\(^{-1}\)) than the non-elite athletes (P<0.01). There was a main effect of maturation with the more mature athletes having a higher peak oxygen uptake (l.min\(^{-1}\)) (P<0.01). Elite T2 (2.27 ± 0.13 l.min\(^{-1}\)), T4 (2.83 ± 0.07 l.min\(^{-1}\)), T5 (2.97 ± 0.07 l.min\(^{-1}\)). Non-Elite T2 (2.09 ± 0.19 l.min\(^{-1}\)), T5 (2.51 ± 0.07 l.min\(^{-1}\)). [Figure 5.1] There was also main effect of age with the older athletes having a higher peak oxygen uptake (l.min\(^{-1}\)) (P<0.01). Elite 12 y (1.98 ± 0.1 l.min\(^{-1}\)), 14 y (2.82 ± 0.1 l.min\(^{-1}\)), 16 y (3.1 ± 0.07 l.min\(^{-1}\)), Non-Elite 12 y (2.11 ± 0.11 l.min\(^{-1}\)), 14 y (2.55 ± 0.09 l.min\(^{-1}\)), 16 y (2.56 ± 0.11 l.min\(^{-1}\)). [Figure 5.2]

When peak oxygen uptake was scaled by body mass the elite athletes had a higher peak oxygen uptake (ml.kg\(^{-1}\).min\(^{-1}\)) than the non-elite athletes (P<0.01 main effect of group), but there was no effect of maturation status. [Table 5.2] or of age [Table 5.3]

The elite athletes have lower maximum heart rates (beats.min\(^{-1}\)) than the non-elite athletes (P<0.01 main effect of group) but there is no effect of maturation. [Figure: 5.3] or of age [Figure: 5.4]

When the elite athlete subsets' peak performances were analysed there were no significant differences in peak oxygen uptake (l.min\(^{-1}\)), maximum heart rate (beats.min\(^{-1}\)) or maximum R value achieved. There was a main effect of group (P<0.01) in ratio scaled peak oxygen uptake (ml.kg\(^{-1}\).min\(^{-1}\)) with the 'individual endurance' athletes having a higher peak oxygen uptake (ml.kg\(^{-1}\).min\(^{-1}\)) than each of the other elite groups. [Table 5.4]
Figure: 5.1 Peak Oxygen Uptake (l.min\(^{-1}\)) for elite and non-elite adolescent female sports performers by Tanner stage (PH) (mean ± SE). P<0.01

Figure: 5.2 Peak Oxygen Uptake (l.min\(^{-1}\)) for elite and non-elite adolescent female sports performers by age (mean ± SE). P<0.01
Table 5.2  Peak oxygen uptake (ml.kg-1.min-1) for elite and non-elite adolescent female sports performers by Tanner stage (PH) (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Tanner Stg 2 (Pubic Hair)</th>
<th>Tanner Stg 3 (Pubic Hair)</th>
<th>Tanner Stg 4 (Pubic Hair)</th>
<th>Tanner Stg 5 (Pubic Hair)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite</td>
<td></td>
<td></td>
<td></td>
<td>Main Effect</td>
</tr>
<tr>
<td></td>
<td>49.63 ± 1.35</td>
<td>50.40 ± 1.11</td>
<td>50.09 ± 1.18</td>
<td>(10)</td>
</tr>
<tr>
<td></td>
<td>(10)</td>
<td>(16)</td>
<td>(22)</td>
<td>Group P&lt;0.01</td>
</tr>
<tr>
<td>Non-Elite</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>47.86 ± 3.87</td>
<td>45.40 ± 1.69</td>
<td>43.41 ± 0.81</td>
<td>(7)</td>
</tr>
<tr>
<td></td>
<td>(7)</td>
<td>(16)</td>
<td>(39)</td>
<td>(30)</td>
</tr>
</tbody>
</table>

Table 5.3  Peak oxygen uptake (ml.kg-1.min-1) for elite and non-elite adolescent female sports performers by age (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Group</th>
<th>12 years</th>
<th>13 years</th>
<th>14 years</th>
<th>15 years</th>
<th>16 years</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite</td>
<td>49.48 ± 1.28</td>
<td>50.50 ± 1.64</td>
<td>49.52 ± 1.22</td>
<td>48.51 ± 1.65</td>
<td>48.19 ± 1.06</td>
<td>Main Effect</td>
</tr>
<tr>
<td></td>
<td>(6)</td>
<td>(13)</td>
<td>(21)</td>
<td>(21)</td>
<td>(18)</td>
<td>Group P&lt;0.01</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>45.68 ± 1.36</td>
<td>43.83 ± 1.15</td>
<td>45.62 ± 1.49</td>
<td>43.88 ± 1.29</td>
<td>44.15 ± 1.65</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(10)</td>
<td>(22)</td>
<td>(21)</td>
<td>(30)</td>
<td>(12)</td>
<td></td>
</tr>
</tbody>
</table>
Figure 5.3 Maximum heart rate (beats.min\textsuperscript{-1}) for elite and non-elite adolescent female sports performers by Tanner stage (PH) (mean ± SE). P<0.01

Figure 5.4 Maximum Heart Rate (beats.min\textsuperscript{-1}) for elite and non-elite adolescent female sports performers by age (mean ± SE). P<0.01
Table 5.4  Peak oxygen uptake (l.min⁻¹) and peak oxygen uptake (ml.kg⁻¹.min⁻¹), maximum heart rate (beats.min⁻¹) and maximum R value, for elite adolescent female sports performers in the following groups ‘team players’, elite ‘individual endurance’ athletes, elite ‘individual games players’ and elite ‘individual athletes from other disciplines’ (mean ± SE) by group. Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Team Players</th>
<th>Individual Endurance</th>
<th>Individual Games</th>
<th>Individual Other</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak VO₂ (l.min⁻¹)</td>
<td>2.82 ± 0.09</td>
<td>2.85 ± 0.08</td>
<td>2.72 ± 0.14</td>
<td>2.62 ± 0.10</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>(32)</td>
<td>(14)</td>
<td>(14)</td>
<td>(20)</td>
<td></td>
</tr>
<tr>
<td>Peak VO₂ (ml.kg⁻¹.min⁻¹)</td>
<td>47.5 ± 0.8</td>
<td>55.6 ± 0.9</td>
<td>49.3 ± 2.3</td>
<td>47.5 ± 0.8</td>
<td>P&lt;0.01 a</td>
</tr>
<tr>
<td></td>
<td>(32)</td>
<td>(14)</td>
<td>(14)</td>
<td>(20)</td>
<td></td>
</tr>
<tr>
<td>Maximum Heart Rate</td>
<td>199 ± 1</td>
<td>199 ± 2</td>
<td>201 ± 2</td>
<td>200 ± 1</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>(35)</td>
<td>(14)</td>
<td>(14)</td>
<td>(20)</td>
<td></td>
</tr>
<tr>
<td>Maximum R value</td>
<td>1.09 ± 0.01</td>
<td>1.05 ± 0.02</td>
<td>1.10 ± 0.03</td>
<td>1.08 ± 0.01</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>(35)</td>
<td>(14)</td>
<td>(14)</td>
<td>(20)</td>
<td></td>
</tr>
<tr>
<td>Post Hoc:</td>
<td>a</td>
<td>Team v Individual Endurance P&lt;0.01</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Individual Endurance v Individual Games P&lt;0.05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Individual Endurance v Individual Other P&lt;0.01</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.3.3 Submaximal Treadmill Running

The results for all of the variables derived from the submaximal treadmill running test are shown in tables 5.5 to 5.23 for both elite and non-elite adolescent female sports performers and also for the elite adolescent sports performers subsets.

The elite girls had a lower oxygen uptake (ml.kg\(^{-1}\).min\(^{-1}\)) when undertaking submaximal treadmill running at three treadmill (8.0, 9.0 and 10.0 km.h\(^{-1}\)) speeds than did the non-elite girls (P<0.05) when compared by age. There was an interaction of group x age (P<0.05) with the youngest elite athletes having significantly higher submaximal oxygen uptake (ml.kg\(^{-1}\).min\(^{-1}\)) than the oldest girls (P<0.05). There was no effect when analysed by maturation [Table 5.5 and Table 5.6]

There were no differences between the subsets of elite athletes for oxygen uptake (ml.kg\(^{-1}\).min\(^{-1}\)) when undertaking submaximal treadmill running at three treadmill (8.0, 9.0 and 10.0 km.h\(^{-1}\)) speeds [Table 5.7].

There were no differences for running economy (ml.kg\(^{-1}\).km\(^{-1}\)) at three treadmill (8.0, 9.0 and 10.0 km.h\(^{-1}\)) speeds between the elite athlete subsets. [Table 5.8]

The elite athletes had lower blood lactate concentration than the non-elite athletes (main effect group P<0.01) when treadmill running at three speeds (8.0, 9.0 and 10.0 km.h\(^{-1}\)). Neither maturation status nor age had an effect on blood lactate concentration. [Table 5.9 and Table 5.10]

When the elite subsets were analysed there was a main effect of group (P<0.01) with the individual endurance athletes producing less blood lactate (mmol.l\(^{-1}\)) (P<0.05) when treadmill running at three speeds (8.0, 9.0 and 10.0 km.h\(^{-1}\)) than either the team players or the individual other group of athletes. [Table 5.11]

The elite athletes had lower heart rates (beats.min\(^{-1}\)) during submaximal treadmill running than the non-elite athletes (P<0.01); when analysed by maturation status and by age. There was no effect of maturation, however there was an effect of age (P<0.05).
There was also an interaction of maturation x group (P<0.01) and an interaction of age x group (P<0.01). [Table 5.12 and Table 5.13] showing that more mature and older elite athletes had lower heart rates (beats.min⁻¹) during submaximal treadmill running.

When the elite athlete subsets were analysed there was a main effect of group (P<0.01), with the individual endurance athletes having lower heart rates during submaximal treadmill running at three (8.0, 9.0 and 10.0 km.h⁻¹) speeds than the team players and the individual other subset of athletes. [Table 5.14]

When heart rate as a percentage of maximum heart rate was analysed during treadmill running at three speeds (8.0, 9.0, and 10.0 km.h⁻¹) the elite athletes ran at lower percentages of their maximum heart rate than the non-elite athletes of the same maturation status (P<0.01). When analysed by age there was a tendency (P=0.055) for the elite athletes to run at a lower percentage of their maximum heart rates than non-elite athletes of the same age. [Table 5.15 and Table 5.16]

Within the subsets of the elite athletes there was a main effect of group (P<0.01) with the individual endurance athletes running at lower percentages of their maximum heart rate than the team players and the individual other group. The individual games players ran at lower percentages of their maximum heart rate than the individual other group. [Table 5.17]

The elite athletes reported lower rates of perceived exertion during submaximal treadmill running at 3 speeds (8.0, 9.0, and 10.0 km.h⁻¹) than the non-elite athletes for both maturation status and age (P<0.01). There was an interaction of group x maturation status (P<0.01) and an interaction of group x age (P<0.01). [Table 5.18 and Table 5.19]

Within the elite athlete subsets there was a main effect of group (P<0.05) with the individual endurance athletes reporting lower rates of perceived exertion when running three stages at 8.0, 9.0 and 10.0 km.h⁻¹ on the treadmill at than the team players. [Table 5.20]
The elite athletes had a lower RVvalue than the non-elite athletes when analysed by maturation status (P<0.01), however there was no effect of maturation. When the results were analysed by age there was a tendency (P=0.052) for the elite athletes to have a lower R Value than the non-elite athletes. There was a main effect of age (P<0.01), with an interaction of group and age (P<0.05), showing that the older elite girls had lower R Values than the older non-elite girls. [Table 5.21 and Table 5.22]

In the elite athlete subsets there was a main effect of group (P<0.01) with the individual endurance athletes having lower RVvalues than the team players and the individual other subset. [Table 5.23]
Table 5.5  Oxygen uptake (ml.kg⁻¹.min⁻¹) at three treadmill (8.0, 9.0 and 10.0 km.h⁻¹) speeds for elite and non-elite adolescent female sports performers by Tanner stage (PH) (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Tanner Stg 2 (Pubic Hair)</th>
<th>Tanner Stg 3 (Pubic Hair)</th>
<th>Tanner Stg 4 (Pubic Hair)</th>
<th>Tanner Stg 5 (Pubic Hair)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite 8.0 km.h⁻¹</td>
<td></td>
<td></td>
<td></td>
<td>NS</td>
</tr>
<tr>
<td>33.8 ± 1.0 (8)</td>
<td>33.1 ± 0.8 (12)</td>
<td>32.3 ± 0.6 (22)</td>
<td>31.9 ± 0.4 (16)</td>
<td></td>
</tr>
<tr>
<td>Non-Elite 8.0 km.h⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>36.6 ± 2.2 (4)</td>
<td>33.4 ± 1.0 (11)</td>
<td>31.6 ± 0.5 (25)</td>
<td>31.2 ± 0.7 (15)</td>
<td></td>
</tr>
<tr>
<td>Elite 9.0 km.h⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>37.0 ± 1.2 (8)</td>
<td>36.0 ± 1.0 (12)</td>
<td>34.8 ± 0.4 (22)</td>
<td>34.9 ± 0.4 (16)</td>
<td></td>
</tr>
<tr>
<td>Non-Elite 9.0 km.h⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>38.4 ± 2.77 (4)</td>
<td>36.2 ± 1.0 (11)</td>
<td>34.5 ± 0.5 (25)</td>
<td>34.2 ± 0.7 (15)</td>
<td></td>
</tr>
<tr>
<td>Elite 10.0 km.h⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>39.1 ± 1.0 (8)</td>
<td>38.7 ± 1.0 (12)</td>
<td>37.6 ± 0.6 (22)</td>
<td>37.9 ± 0.4 (16)</td>
<td></td>
</tr>
<tr>
<td>Non-Elite 10.0 km.h⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40.1 ± 3.36 (4)</td>
<td>39.4 ± 1.18 (11)</td>
<td>36.8 ± 0.6 (25)</td>
<td>37.4 ± 0.7 (15)</td>
<td></td>
</tr>
</tbody>
</table>
Chapter 5

Treadmill Running

Table 5.6 Oxygen uptake (ml.kg⁻¹. min⁻¹) at three treadmill (8.0, 9.0 and 10.0 km.h⁻¹) speeds for elite and non-elite adolescent female sports performers by age (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Group</th>
<th>12 years</th>
<th>13 years</th>
<th>14 years</th>
<th>15 years</th>
<th>16 years</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite 8.0 km.h⁻¹</td>
<td>37.8 ± 0.6</td>
<td>32.5 ± 0.6</td>
<td>32.2 ± 0.6</td>
<td>32.4 ± 0.5</td>
<td>31.2 ± 0.5</td>
<td>Main Effect</td>
</tr>
<tr>
<td></td>
<td>(3)</td>
<td>(11)</td>
<td>(16)</td>
<td>(21)</td>
<td>(18)</td>
<td>Group P&lt;0.05</td>
</tr>
<tr>
<td>Non-Elite 8.0 km.h⁻¹</td>
<td>31.6 ± 0.9</td>
<td>33.1 ± 1.2</td>
<td>32.5 ± 1.0</td>
<td>32.0 ± 0.7</td>
<td>31.9 ± 0.7</td>
<td>Main Effect</td>
</tr>
<tr>
<td></td>
<td>(10)</td>
<td>(9)</td>
<td>(15)</td>
<td>(17)</td>
<td>(6)</td>
<td>Group x Age P&lt;0.05</td>
</tr>
<tr>
<td>Elite 9.0 km.h⁻¹</td>
<td>41.1 ± 0.2</td>
<td>35.4 ± 0.6</td>
<td>35.4 ± 0.6</td>
<td>35.5 ± 0.5</td>
<td>33.8 ± 0.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(3)</td>
<td>(11)</td>
<td>(16)</td>
<td>(21)</td>
<td>(18)</td>
<td></td>
</tr>
<tr>
<td>Non-Elite 9.0 km.h⁻¹</td>
<td>34.2 ± 0.9</td>
<td>35.5 ± 1.3</td>
<td>35.7 ± 0.9</td>
<td>34.9 ± 0.7</td>
<td>34.5 ± 1.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(10)</td>
<td>(9)</td>
<td>(15)</td>
<td>(17)</td>
<td>(6)</td>
<td></td>
</tr>
<tr>
<td>Elite 10.0 km.h⁻¹</td>
<td>42.1 ± 0.9</td>
<td>38.3 ± 0.7</td>
<td>38.2 ± 0.7</td>
<td>38.1 ± 0.5</td>
<td>36.9 ± 0.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(3)</td>
<td>(11)</td>
<td>(16)</td>
<td>(21)</td>
<td>(18)</td>
<td></td>
</tr>
<tr>
<td>Non-Elite 10.0 km.h⁻¹</td>
<td>36.8 ± 1.0</td>
<td>37.7 ± 1.6</td>
<td>38.4 ± 0.9</td>
<td>37.9 ± 0.8</td>
<td>37.1 ± 1.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(10)</td>
<td>(9)</td>
<td>(15)</td>
<td>(17)</td>
<td>(6)</td>
<td></td>
</tr>
<tr>
<td>Post Hoc:</td>
<td>12 yr v 16 yr</td>
<td>P&lt;0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 5.7 Oxygen uptake (ml.kg⁻¹.min⁻¹) at three treadmill (8.0, 9.0 and 10.0 km.hr⁻¹) speeds in elite adolescent female sports performers (70) in the following groups: 'team players', elite 'individual endurance' athletes, elite 'individual game players' and elite 'individual athletes from other disciplines' (mean ± SE) by group. Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Treadmill Speed</th>
<th>Team Players</th>
<th>Individual Endurance</th>
<th>Individual Games</th>
<th>Individual Other</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.00 (km.hr⁻¹)</td>
<td>31.8 ± 0.5</td>
<td>32.8 ± 0.6</td>
<td>31.2 ± 0.6</td>
<td>33.6 ± 0.6</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>(30)</td>
<td>(16)</td>
<td>(11)</td>
<td>(13)</td>
<td></td>
</tr>
<tr>
<td>9.00 (km.hr⁻¹)</td>
<td>34.7 ± 0.5</td>
<td>35.4 ± 0.6</td>
<td>34.0 ± 0.5</td>
<td>36.8 ± 0.7</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>(30)</td>
<td>(16)</td>
<td>(11)</td>
<td>(13)</td>
<td></td>
</tr>
<tr>
<td>10.00 (km.hr⁻¹)</td>
<td>37.5 ± 0.4</td>
<td>38.7 ± 0.6</td>
<td>36.9 ± 0.5</td>
<td>39.3 ± 0.8</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>(30)</td>
<td>(16)</td>
<td>(11)</td>
<td>(13)</td>
<td></td>
</tr>
</tbody>
</table>
Table 5.8  Running Economy (ml.kg⁻¹.km⁻¹) at three treadmill (8.0, 9.0 and 10.0 km.h⁻¹) speeds in elite adolescent female sports performers (70) in the following groups: 'team players', elite 'individual endurance' athletes, elite 'individual game players' and elite 'individual athletes from other disciplines' (mean ± SE) by group. Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Treadmill Speed</th>
<th>Team Players</th>
<th>Individual Endurance</th>
<th>Individual Games</th>
<th>Individual Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.00 (km.hr⁻¹)</td>
<td>237 ± 3</td>
<td>246 ± 5</td>
<td>235 ± 4</td>
<td>252 ± 5</td>
</tr>
<tr>
<td></td>
<td>(30)</td>
<td>(16)</td>
<td>(11)</td>
<td>(13)</td>
</tr>
<tr>
<td>9.00 (km.hr⁻¹)</td>
<td>232 ± 3</td>
<td>236 ± 4</td>
<td>229 ± 4</td>
<td>246 ± 5</td>
</tr>
<tr>
<td></td>
<td>(30)</td>
<td>(16)</td>
<td>(11)</td>
<td>(13)</td>
</tr>
<tr>
<td>10.00 (km.hr⁻¹)</td>
<td>227 ± 2</td>
<td>233 ± 4</td>
<td>223 ± 5</td>
<td>236 ± 5</td>
</tr>
<tr>
<td></td>
<td>(30)</td>
<td>(16)</td>
<td>(11)</td>
<td>(13)</td>
</tr>
</tbody>
</table>
Chapter 5  

**Treadmill Running**

Table: 5.9  
Blood lactate concentrations (mmol.l-1) at three treadmill (8.0, 9.0 and 10.0 km.h⁻¹) speeds for elite and non-elite adolescent female sports performers by Tanner stage (PH) (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Tanner Stage</th>
<th>8.0 km.h⁻¹</th>
<th>9.0 km.h⁻¹</th>
<th>10.0 km.h⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 (Pubic Hair)</td>
<td>1.99 ± 0.31</td>
<td>2.0 ± 0.3</td>
<td>3.4 ± 0.5</td>
</tr>
<tr>
<td>3 (Pubic Hair)</td>
<td>1.90 ± 0.23</td>
<td>2.0 ± 0.3</td>
<td>2.7 ± 0.4</td>
</tr>
<tr>
<td>4 (Pubic Hair)</td>
<td>1.84 ± 0.17</td>
<td>2.0 ± 0.3</td>
<td>2.7 ± 0.4</td>
</tr>
<tr>
<td>5 (Pubic Hair)</td>
<td>2.21 ± 0.20</td>
<td>2.6 ± 0.3</td>
<td>3.5 ± 0.5</td>
</tr>
<tr>
<td>Non-Elite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 (Pubic Hair)</td>
<td>3.11 ± 0.98</td>
<td>3.4 ± 0.3</td>
<td>4.7 ± 1.6</td>
</tr>
<tr>
<td>3 (Pubic Hair)</td>
<td>3.05 ± 0.24</td>
<td>3.0 ± 0.2</td>
<td>5.0 ± 0.3</td>
</tr>
<tr>
<td>4 (Pubic Hair)</td>
<td>2.77 ± 0.19</td>
<td>3.0 ± 0.2</td>
<td>4.5 ± 0.4</td>
</tr>
<tr>
<td>5 (Pubic Hair)</td>
<td>3.10 ± 0.32</td>
<td>3.6 ± 0.3</td>
<td>4.4 ± 0.4</td>
</tr>
</tbody>
</table>

**Significance**

- Main Effect
- Group P<0.01
Table: 5.10  Blood lactate concentrations (mmol.l\(^{-1}\)) at three treadmill (8.0, 9.0 and 10.0 km.h\(^{-1}\)) speeds for elite and non-elite adolescent female sports performers (mean ± SE) by Tanner stage (PH) and by age. Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Group</th>
<th>12 years</th>
<th>13 years</th>
<th>14 years</th>
<th>15 years</th>
<th>16 years</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite 8.0 km.h(^{-1})</td>
<td>3.0 ± 0.3</td>
<td>2.0 ± 0.4</td>
<td>1.4 ± 0.2</td>
<td>2.2 ± 0.2</td>
<td>2.4 ± 0.2</td>
<td>Main Effect Group P&lt;0.01</td>
</tr>
<tr>
<td>Non-Elite 8.0 km.h(^{-1})</td>
<td>2.5 ± 0.4</td>
<td>3.1 ± 0.4</td>
<td>3.2 ± 0.4</td>
<td>2.8 ± 0.2</td>
<td>2.8 ± 0.4</td>
<td></td>
</tr>
<tr>
<td>Elite 9.0 km.h(^{-1})</td>
<td>4.2 ± 0.6</td>
<td>2.0 ± 0.3</td>
<td>1.6 ± 0.2</td>
<td>2.4 ± 0.3</td>
<td>2.9 ± 0.4</td>
<td></td>
</tr>
<tr>
<td>Non-Elite 9.0 km.h(^{-1})</td>
<td>2.6 ± 0.3</td>
<td>3.1 ± 0.4</td>
<td>3.4 ± 0.4</td>
<td>3.4 ± 0.2</td>
<td>3.3 ± 0.4</td>
<td></td>
</tr>
<tr>
<td>Elite 10.0 km.h(^{-1})</td>
<td>5.1 ± 0.3</td>
<td>2.7 ± 0.4</td>
<td>2.2 ± 0.2</td>
<td>3.3 ± 0.4</td>
<td>3.8 ± 0.6</td>
<td></td>
</tr>
<tr>
<td>Non-Elite 10.0 km.h(^{-1})</td>
<td>3.7 ± 0.6</td>
<td>4.2 ± 0.6</td>
<td>4.9 ± 0.6</td>
<td>4.8 ± 0.4</td>
<td>4.9 ± 0.6</td>
<td></td>
</tr>
</tbody>
</table>
Table 5.11  Blood lactate concentrations (mmol.l⁻¹) at three treadmill (8.0, 9.0 and 10.0 km.h⁻¹) speeds in elite adolescent female sports performers (68) in the following groups: 'team players', elite 'individual endurance' athletes, elite 'individual game players' and elite 'individual athletes from other disciplines' (mean ± SE) by group. Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Treadmill Speed</th>
<th>Team Players</th>
<th>Individual Endurance</th>
<th>Individual Games</th>
<th>Individual Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.00 (km.h⁻¹)</td>
<td>2.2 ± 0.1</td>
<td>1.6 ± 0.2</td>
<td>1.9 ± 0.2</td>
<td>2.5 ± 0.2</td>
</tr>
<tr>
<td></td>
<td>(30)</td>
<td>(15)</td>
<td>(10)</td>
<td>(12)</td>
</tr>
<tr>
<td>9.00 (km.h⁻¹)</td>
<td>2.8 ± 0.3</td>
<td>1.4 ± 0.2</td>
<td>2.0 ± 0.3</td>
<td>3.0 ± 0.3</td>
</tr>
<tr>
<td></td>
<td>(30)</td>
<td>(15)</td>
<td>(11)</td>
<td>(12)</td>
</tr>
<tr>
<td>10.00 (km.h⁻¹)</td>
<td>3.5 ± 0.3</td>
<td>1.9 ± 0.3</td>
<td>2.3 ± 0.2</td>
<td>4.1 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>(30)</td>
<td>(15)</td>
<td>(8)</td>
<td>(12)</td>
</tr>
</tbody>
</table>

P<0.01  Main effect: Group
Post Hoc: Team v Individual Endurance P<0.05
Individual Endurance v Individual Other P<0.01
Table 5.12  Heart rate (beats.min⁻¹) at three treadmill (8.0, 9.0 and 10.0 km.h⁻¹) speeds for elite and non-elite adolescent female sports performers by Tanner stage (PH) (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th></th>
<th>Tanner Stg 2 (Pubic Hair)</th>
<th>Tanner Stg 3 (Pubic Hair)</th>
<th>Tanner Stg 4 (Pubic Hair)</th>
<th>Tanner Stg 5 (Pubic Hair)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite 8.0 km.h⁻¹</td>
<td>162 ± 4 (8)</td>
<td>159 ± 3 (12)</td>
<td>160 ± 3 (22)</td>
<td>159 ± 3 (16)</td>
<td>Main Effect Group P&lt;0.01</td>
</tr>
<tr>
<td>Non-Elite 8.0 km.h⁻¹</td>
<td>185 ± 5 (4)</td>
<td>174 ± 4 (11)</td>
<td>171 ± 2 (25)</td>
<td>168 ± 4 (15)</td>
<td>Main Effect Maturation x Group P&lt;0.01</td>
</tr>
<tr>
<td>Elite 9.0 km.h⁻¹</td>
<td>178 ± 4 (8)</td>
<td>169 ± 3 (12)</td>
<td>170 ± 3 (22)</td>
<td>169 ± 3 (16)</td>
<td></td>
</tr>
<tr>
<td>Non-Elite 9.0 km.h⁻¹</td>
<td>170 ± 6 (4)</td>
<td>183 ± 3 (11)</td>
<td>178 ± 2 (25)</td>
<td>180 ± 4 (15)</td>
<td></td>
</tr>
<tr>
<td>Elite 10.0 km.h⁻¹</td>
<td>187 ± 3 (8)</td>
<td>177 ± 3 (12)</td>
<td>178 ± 3 (22)</td>
<td>179 ± 3 (16)</td>
<td></td>
</tr>
<tr>
<td>Non-Elite 10.0 km.h⁻¹</td>
<td>194 ± 7 (4)</td>
<td>191 ± 3 (11)</td>
<td>185 ± 2 (25)</td>
<td>189 ± 3 (15)</td>
<td></td>
</tr>
</tbody>
</table>
Table 5.13  Heart rate (beats.min⁻¹) at three treadmill (8.0, 9.0 and 10.0 km.h⁻¹) speeds for elite and non-elite adolescent female sports performers by age (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Group</th>
<th>12 years</th>
<th>13 years</th>
<th>14 years</th>
<th>15 years</th>
<th>16 years</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.0 km.h⁻¹</td>
<td>177 ± 1</td>
<td>153 ± 4</td>
<td>156 ± 3</td>
<td>163 ± 3</td>
<td>161 ± 3</td>
<td>Main Effect Group P&lt;0.01</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>167 ± 5</td>
<td>166 ± 4</td>
<td>176 ± 3</td>
<td>173 ± 2</td>
<td>170 ± 3</td>
<td>Main Effect Age P&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>(10)</td>
<td>(9)</td>
<td>(15)</td>
<td>(17)</td>
<td>(6)</td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.0 km.h⁻¹</td>
<td>190 ± 2</td>
<td>167 ± 4</td>
<td>168 ± 3</td>
<td>172 ± 3</td>
<td>169 ± 4</td>
<td>Main Effect Age x Group P&lt;0.01</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>176 ± 5</td>
<td>173 ± 3</td>
<td>186 ± 3</td>
<td>182 ± 2</td>
<td>177 ± 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(10)</td>
<td>(9)</td>
<td>(15)</td>
<td>(17)</td>
<td>(6)</td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.0 km.h⁻¹</td>
<td>196 ± 2</td>
<td>178 ± 4</td>
<td>177 ± 3</td>
<td>181 ± 3</td>
<td>178 ± 3</td>
<td></td>
</tr>
<tr>
<td>Non-Elite</td>
<td>184 ± 5</td>
<td>178 ± 3</td>
<td>193 ± 3</td>
<td>192 ± 2</td>
<td>184 ± 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(10)</td>
<td>(9)</td>
<td>(15)</td>
<td>(17)</td>
<td>(6)</td>
<td></td>
</tr>
</tbody>
</table>

Post Hoc: 12 y v 13 y  P<0.05
Table 5.14  Heart rate (beats.min\(^{-1}\)) at three treadmill (8.0, 9.0 and 10.0 km.h\(^{-1}\)) speeds in elite adolescent female sports performers (58) in the following groups: 'team players', elite 'individual endurance' athletes, elite 'individual game players' and elite 'individual athletes from other disciplines' (mean ± SE) by group. Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Treadmill Speed</th>
<th>Team Players n=30</th>
<th>Individual Endurance n=16</th>
<th>Individual Games n=11</th>
<th>Individual Other n=13</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.00 (km.h(^{-1}))</td>
<td>156 ± 7</td>
<td>151 ± 3</td>
<td>156 ± 3</td>
<td>166 ± 3</td>
</tr>
<tr>
<td>9.00 (km.h(^{-1}))</td>
<td>173 ± 7</td>
<td>162 ± 3</td>
<td>166 ± 4</td>
<td>179 ± 3</td>
</tr>
<tr>
<td>10.00 (km.h(^{-1}))</td>
<td>173 ± 8</td>
<td>172 ± 3</td>
<td>175 ± 4</td>
<td>187 ± 3</td>
</tr>
</tbody>
</table>

P<0.01 Main Effect: Group
Post Hoc: Team v Individual Endurance P<0.05
Individual Endurance v Individual Other P<0.01
Table 5.15  Heart Rate (percentage of maximum) at three treadmill (8.0, 9.0 and 10.0 km.h⁻¹) speeds for elite and non-elite adolescent female sports performers by Tanner stage (PH) (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Tanner Stg 2 (Pubic Hair)</th>
<th>Tanner Stg 3 (Pubic Hair)</th>
<th>Tanner Stg 4 (Pubic Hair)</th>
<th>Tanner Stg 5 (Pubic Hair)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite 8.0 km.h⁻¹</td>
<td>82 ± 2</td>
<td>80 ± 2</td>
<td>80 ± 2</td>
<td>80 ± 2</td>
</tr>
<tr>
<td>Non-Elite 8.0 km.h⁻¹</td>
<td>88 ± 1</td>
<td>85 ± 1</td>
<td>85 ± 1</td>
<td>83 ± 2</td>
</tr>
<tr>
<td>Elite 9.0 km.h⁻¹</td>
<td>90 ± 2</td>
<td>85 ± 2</td>
<td>85 ± 1</td>
<td>86 ± 2</td>
</tr>
<tr>
<td>Non-Elite 9.0 km.h⁻¹</td>
<td>90 ± 2</td>
<td>89 ± 1</td>
<td>89 ± 1</td>
<td>89 ± 1</td>
</tr>
<tr>
<td>Elite 10.0 km.h⁻¹</td>
<td>94 ± 2</td>
<td>89 ± 2</td>
<td>90 ± 1</td>
<td>90 ± 2</td>
</tr>
<tr>
<td>Non-Elite 10.0 km.h⁻¹</td>
<td>92 ± 3</td>
<td>93 ± 1</td>
<td>93 ± 1</td>
<td>93 ± 1</td>
</tr>
</tbody>
</table>
Table: 5.16  Heart rate (percentage of maximum) at three treadmill (8.0, 9.0 and 10.0 km.h\(^{-1}\)) speeds for elite and non-elite adolescent female sports performers by age (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Group</th>
<th>12 years</th>
<th>13 years</th>
<th>14 years</th>
<th>15 years</th>
<th>16 years</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite</td>
<td>88 ± 2</td>
<td>78 ± 2</td>
<td>79 ± 2</td>
<td>81 ± 1</td>
<td>81 ± 2</td>
<td>Main Effect Group P&lt;0.05</td>
</tr>
<tr>
<td>8.0 km.h(^{-1})</td>
<td>(3)</td>
<td>(10)</td>
<td>(15)</td>
<td>(17)</td>
<td>(11)</td>
<td></td>
</tr>
<tr>
<td>Non-Elite</td>
<td>82 ± 2</td>
<td>83 ± 2</td>
<td>86 ± 1</td>
<td>85 ± 1</td>
<td>84 ± 2</td>
<td>Main Effect Group x Age P=0.053</td>
</tr>
<tr>
<td>8.0 km.h(^{-1})</td>
<td>(9)</td>
<td>(8)</td>
<td>(14)</td>
<td>(17)</td>
<td>(6)</td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td>94 ± 1</td>
<td>84 ± 3</td>
<td>86 ± 2</td>
<td>86 ± 1</td>
<td>85 ± 2</td>
<td></td>
</tr>
<tr>
<td>9.0 km.h(^{-1})</td>
<td>(3)</td>
<td>(10)</td>
<td>(15)</td>
<td>(17)</td>
<td>(11)</td>
<td></td>
</tr>
<tr>
<td>Non-Elite</td>
<td>87 ± 2</td>
<td>87 ± 1</td>
<td>91 ± 1</td>
<td>89 ± 1</td>
<td>88 ± 2</td>
<td></td>
</tr>
<tr>
<td>9.0 km.h(^{-1})</td>
<td>(9)</td>
<td>(8)</td>
<td>(14)</td>
<td>(17)</td>
<td>(6)</td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td>97 ± 2</td>
<td>90 ± 2</td>
<td>90 ± 2</td>
<td>90 ± 1</td>
<td>90 ± 2</td>
<td></td>
</tr>
<tr>
<td>10.0 km.h(^{-1})</td>
<td>(3)</td>
<td>(10)</td>
<td>(15)</td>
<td>(17)</td>
<td>(11)</td>
<td></td>
</tr>
<tr>
<td>Non-Elite</td>
<td>92 ± 2</td>
<td>90 ± 1</td>
<td>94 ± 1</td>
<td>94 ± 1</td>
<td>91 ± 2</td>
<td></td>
</tr>
<tr>
<td>10.0 km.h(^{-1})</td>
<td>(9)</td>
<td>(8)</td>
<td>(14)</td>
<td>(17)</td>
<td>(6)</td>
<td></td>
</tr>
</tbody>
</table>
Table 5.17 Heart rate (percentage of maximal) at three treadmill (8.0, 9.0 and 10.0 km.h⁻¹) speeds in elite adolescent female sports performers (57) in the following groups: 'team players', elite 'individual endurance' athletes, elite 'individual game players' and elite 'individual athletes from other disciplines' (mean ± SE) by group. Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Treadmill Speed</th>
<th>Team Players</th>
<th>Individual Endurance</th>
<th>Individual Games</th>
<th>Individual Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.00 (km.hr⁻¹)</td>
<td>82 ± 1</td>
<td>76 ± 1</td>
<td>77 ± 1</td>
<td>84 ± 1</td>
</tr>
<tr>
<td></td>
<td>(23)</td>
<td>(15)</td>
<td>(6)</td>
<td>(13)</td>
</tr>
<tr>
<td>9.00 (km.hr⁻¹)</td>
<td>87 ± 1</td>
<td>82 ± 1</td>
<td>81 ± 1</td>
<td>91 ± 1</td>
</tr>
<tr>
<td></td>
<td>(23)</td>
<td>(15)</td>
<td>(6)</td>
<td>(13)</td>
</tr>
<tr>
<td>10.00 (km.hr⁻¹)</td>
<td>91 ± 1</td>
<td>87 ± 1</td>
<td>86 ± 2</td>
<td>95 ± 1</td>
</tr>
<tr>
<td></td>
<td>(23)</td>
<td>(15)</td>
<td>(6)</td>
<td>(13)</td>
</tr>
</tbody>
</table>

P<0.01 Main Effect: Group

Post Hoc: Team v Individual Endurance P<0.05
Individual Endurance v Individual Other P<0.01
Individual Games v Individual Other P<0.01
Table 5.18 Rate of Perceived Exertion (Borg, 1982) at three treadmill (8.0, 9.0 and 10.0 km.h\(^{-1}\)) speeds for elite and non-elite adolescent female sports performers by Tanner stage (PH) (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th></th>
<th>Tanner Stg 2 (Pubic Hair)</th>
<th>Tanner Stg 3 (Pubic Hair)</th>
<th>Tanner Stg 4 (Pubic Hair)</th>
<th>Tanner Stg 5 (Pubic Hair)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite 8.0 km.h(^{-1})</td>
<td>9 ± 1</td>
<td>10 ± 1</td>
<td>9 ± 0.5</td>
<td>10 ± 0.5</td>
<td>Main Effect Group</td>
</tr>
<tr>
<td></td>
<td>(8)</td>
<td>(12)</td>
<td>(22)</td>
<td>(16)</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>Non-Elite 8.0 km.h(^{-1})</td>
<td>11 ± 1</td>
<td>11 ± 0.5</td>
<td>11 ± 0.5</td>
<td>11 ± 0.5</td>
<td>Main Effect Group x Maturation</td>
</tr>
<tr>
<td></td>
<td>(4)</td>
<td>(11)</td>
<td>(25)</td>
<td>(15)</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>Elite 9.0 km.h(^{-1})</td>
<td>11 ± 1</td>
<td>11 ± 0.5</td>
<td>11 ± 0.5</td>
<td>12 ± 0.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(8)</td>
<td>(12)</td>
<td>(22)</td>
<td>(16)</td>
<td></td>
</tr>
<tr>
<td>Non-Elite 9.0 km.h(^{-1})</td>
<td>12 ± 1</td>
<td>12 ± 1</td>
<td>12 ± 0.5</td>
<td>13 ± 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(4)</td>
<td>(11)</td>
<td>(25)</td>
<td>(15)</td>
<td></td>
</tr>
<tr>
<td>Elite 10.0 km.h(^{-1})</td>
<td>15 ± 0.5</td>
<td>12 ± 0.5</td>
<td>13 ± 0.5</td>
<td>13 ± 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(8)</td>
<td>(12)</td>
<td>(22)</td>
<td>(16)</td>
<td></td>
</tr>
<tr>
<td>Non-Elite 10.0 km.h(^{-1})</td>
<td>14 ± 1</td>
<td>14 ± 1</td>
<td>13 ± 0.5</td>
<td>14 ± 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(4)</td>
<td>(11)</td>
<td>(25)</td>
<td>(15)</td>
<td></td>
</tr>
</tbody>
</table>
Table: 5.19 Rate of Perceived Exertion (Borg, 1982) at three treadmill (8.0, 9.0 and 10.0 km.h\(^{-1}\)) speeds for elite and non-elite adolescent female sports performers by age (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Group</th>
<th>12 years</th>
<th>13 years</th>
<th>14 years</th>
<th>15 years</th>
<th>16 years</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite 8.0 km.h(^{-1})</td>
<td>7 ± 1 (3)</td>
<td>9 ± 1 (10)</td>
<td>9 ± 1 (15)</td>
<td>10 ± 1 (18)</td>
<td>10 ± 1 (12)</td>
<td>Main Effect Group P&lt;0.01</td>
</tr>
<tr>
<td>Non-Elite 8.0 km.h(^{-1})</td>
<td>10 ± 1 (10)</td>
<td>10 ± 1 (9)</td>
<td>11 ± 1 (15)</td>
<td>11 ± 1 (17)</td>
<td>12 ± 1 (6)</td>
<td>Main Effect Group x Age P&lt;0.01</td>
</tr>
<tr>
<td>Elite 9.0 km.h(^{-1})</td>
<td>11 ± 1 (3)</td>
<td>10 ± 1 (10)</td>
<td>11 ± 0.5 (15)</td>
<td>11 ± 1 (18)</td>
<td>12 ± 1 (12)</td>
<td></td>
</tr>
<tr>
<td>Non-Elite 9.0 km.h(^{-1})</td>
<td>12 ± 1 (10)</td>
<td>11 ± 1 (9)</td>
<td>13 ± 0.5 (15)</td>
<td>12 ± 1 (17)</td>
<td>13 ± 1 (6)</td>
<td></td>
</tr>
<tr>
<td>Elite 10.0 km.h(^{-1})</td>
<td>13 ± 1 (3)</td>
<td>13 ± 1 (10)</td>
<td>13 ± 1 (15)</td>
<td>13 ± 1 (18)</td>
<td>14 ± 1 (12)</td>
<td></td>
</tr>
<tr>
<td>Non-Elite 10.0 km.h(^{-1})</td>
<td>13 ± 1 (10)</td>
<td>12 ± 1 (9)</td>
<td>14 ± 1 (15)</td>
<td>14 ± 1 (17)</td>
<td>14 ± 1 (6)</td>
<td></td>
</tr>
</tbody>
</table>
Table 5.20 Rate of Perceived Exertion at three treadmill (8.0, 9.0 and 10.0 km.h\(^{-1}\)) speeds in elite adolescent female sports performers (59) in the following groups: ‘team players’, elite ‘individual endurance’ athletes, elite ‘individual game players’ and elite ‘individual athletes from other disciplines’ (mean ± SE) by group. Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Treadmill Speed</th>
<th>Team Players</th>
<th>Individual Endurance</th>
<th>Individual Games</th>
<th>Individual Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.00 (km.hr(^{-1}))</td>
<td>10 ± 0 (24)</td>
<td>9 ± 0 (16)</td>
<td>9 ± 1 (6)</td>
<td>9 ± 1 (13)</td>
</tr>
<tr>
<td>9.00 (km.hr(^{-1}))</td>
<td>12 ± 0 (24)</td>
<td>10 ± 0 (16)</td>
<td>10 ± 1 (6)</td>
<td>12 ± 0 (13)</td>
</tr>
<tr>
<td>10.00 (km.hr(^{-1}))</td>
<td>13 ± 0 (24)</td>
<td>12 ± 0 (16)</td>
<td>12 ± 1 (6)</td>
<td>14 ± 1 (13)</td>
</tr>
</tbody>
</table>

\(P<0.05\) Main Effect Group

Post Hoc: Team v Individual Endurance \(P<0.05\)
Table 5.21  R value at three treadmill (8.0, 9.0 and 10.0 km.h⁻¹) speeds for elite and non-elite adolescent female sports performers by Tanner stage (PH) (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th></th>
<th>Tanner Stg 2 (Pubic Hair)</th>
<th>Tanner Stg 3 (Pubic Hair)</th>
<th>Tanner Stg 4 (Pubic Hair)</th>
<th>Tanner Stg 5 (Pubic Hair)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite</td>
<td>0.93 ± 0.03</td>
<td>0.92 ± 0.01</td>
<td>0.92 ± 0.01</td>
<td>0.93 ± 0.01</td>
<td>Main Effect Group</td>
</tr>
<tr>
<td>8.0 km.h⁻¹</td>
<td>(8)</td>
<td>(12)</td>
<td>(22)</td>
<td>(16)</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>0.95 ± 0.01</td>
<td>0.97 ± 0.02</td>
<td>0.95 ± 0.01</td>
<td>0.97 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>8.0 km.h⁻¹</td>
<td>(4)</td>
<td>(11)</td>
<td>(25)</td>
<td>(15)</td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td>0.93 ± 0.02</td>
<td>0.93 ± 0.01</td>
<td>0.94 ± 0.01</td>
<td>0.96 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>9.0 km.h⁻¹</td>
<td>(8)</td>
<td>(12)</td>
<td>(22)</td>
<td>(16)</td>
<td></td>
</tr>
<tr>
<td>Non-Elite</td>
<td>0.97 ± 0.01</td>
<td>0.98 ± 0.01</td>
<td>0.98 ± 0.01</td>
<td>0.98 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>9.0 km.h⁻¹</td>
<td>(4)</td>
<td>(11)</td>
<td>(25)</td>
<td>(15)</td>
<td></td>
</tr>
<tr>
<td>Elite</td>
<td>1.00 ± 0.06</td>
<td>0.95 ± 0.02</td>
<td>0.97 ± 0.01</td>
<td>0.99 ± 0.02</td>
<td></td>
</tr>
<tr>
<td>10.0 km.h⁻¹</td>
<td>(8)</td>
<td>(12)</td>
<td>(22)</td>
<td>(16)</td>
<td></td>
</tr>
<tr>
<td>Non-Elite</td>
<td>0.98 ± 0.02</td>
<td>1.01 ± 0.02</td>
<td>1.01 ± 0.01</td>
<td>1.02 ± 0.02</td>
<td></td>
</tr>
<tr>
<td>10.0 km.h⁻¹</td>
<td>(4)</td>
<td>(11)</td>
<td>(25)</td>
<td>(15)</td>
<td></td>
</tr>
</tbody>
</table>
Table 5.22 R value at three treadmill (8.0, 9.0 and 10.0 km.h⁻¹) speeds for elite and non-elite adolescent female sports performers by age (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Group</th>
<th>12 years</th>
<th>13 years</th>
<th>14 years</th>
<th>15 years</th>
<th>16 years</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite 8.0 km.h⁻¹</td>
<td>0.99 ± 0.04</td>
<td>0.89 ± 0.02</td>
<td>0.91 ± 0.01</td>
<td>0.94 ± 0.01</td>
<td>0.93 ± 0.02</td>
<td>Main Effect Group</td>
</tr>
<tr>
<td>Non-Elite 8.0 km.h⁻¹</td>
<td>0.96 ± 0.01</td>
<td>0.93 ± 0.02</td>
<td>0.96 ± 0.02</td>
<td>0.97 ± 0.01</td>
<td>0.97 ± 0.01</td>
<td>P=0.052</td>
</tr>
<tr>
<td>Elite 9.0 km.h⁻¹</td>
<td>0.99 ± 0.03</td>
<td>0.90 ± 0.02</td>
<td>0.93 ± 0.01</td>
<td>0.96 ± 0.01</td>
<td>0.96 ± 0.02</td>
<td>Main Effect Age</td>
</tr>
<tr>
<td>Non-Elite 9.0 km.h⁻¹</td>
<td>0.99 ± 0.01</td>
<td>0.95 ± 0.02</td>
<td>0.98 ± 0.02</td>
<td>0.99 ± 0.01</td>
<td>0.99 ± 0.01</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>Elite 10.0 km.h⁻¹</td>
<td>1.15 ± 0.13</td>
<td>0.92 ± 0.02</td>
<td>0.95 ± 0.01</td>
<td>0.98 ± 0.01</td>
<td>0.99 ± 0.02</td>
<td>Main Effect Group x Age</td>
</tr>
<tr>
<td>Non-Elite 10.0 km.h⁻¹</td>
<td>1.01 ± 0.01</td>
<td>0.96 ± 0.02</td>
<td>1.01 ± 0.02</td>
<td>1.03 ± 0.01</td>
<td>1.01 ± 0.01</td>
<td>P&lt;0.05</td>
</tr>
<tr>
<td>Post Hoc</td>
<td>12 y v 13 y</td>
<td>P&lt;0.01</td>
<td>12 y v 14 y</td>
<td>P&lt;0.05</td>
<td>13 y v 15 y</td>
<td>P&lt;0.01</td>
</tr>
</tbody>
</table>
Table: 5.23  

<table>
<thead>
<tr>
<th>Treadmill Speed</th>
<th>Team Players</th>
<th>Individual Endurance</th>
<th>Individual Games</th>
<th>Individual Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.00 (km.h⁻¹)</td>
<td>0.94 ± 0.01</td>
<td>0.89 ± 0.01</td>
<td>0.92 ± 0.01</td>
<td>0.94 ± 0.01</td>
</tr>
<tr>
<td>(24)</td>
<td>(16)</td>
<td>(6)</td>
<td>(13)</td>
<td></td>
</tr>
<tr>
<td>9.00 (km.h⁻¹)</td>
<td>0.96 ± 0.01</td>
<td>0.90 ± 0.01</td>
<td>0.93 ± 0.01</td>
<td>0.96 ± 0.02</td>
</tr>
<tr>
<td>(24)</td>
<td>(16)</td>
<td>(6)</td>
<td>(13)</td>
<td></td>
</tr>
<tr>
<td>10.00 (km.h⁻¹)</td>
<td>1.00 ± 0.02</td>
<td>0.92 ± 0.01</td>
<td>0.96 ± 0.02</td>
<td>0.99 ± 0.02</td>
</tr>
<tr>
<td>(24)</td>
<td>(16)</td>
<td>(6)</td>
<td>(13)</td>
<td></td>
</tr>
</tbody>
</table>

P<0.01 Main Effect: Group
Post Hoc: Team v Individual Endurance P<0.01
Individual Endurance v Individual Other P<0.05
5.4 Discussion

The results presented in this chapter show that the elite athletes had higher peak oxygen uptakes (l.min\(^{-1}\)) and lower maximum heart rates (beat.min\(^{-1}\)), than the non-elite performers (P<0.01) and that there was an effect of maturation and age (P<0.01) for peak VO\(_2\) so that as athletes matured and aged peak VO\(_2\) increased. When peak oxygen uptake was scaled by body mass (ml.kg.min\(^{-1}\)) the elite athletes still had higher values than the non-elite girls (P<0.01) but there was no longer an effect of age or maturation. The elite athletes, when analysed by their subsets, only showed a difference between the subsets for peak oxygen uptake (ml. kg\(^{-1}\).min\(^{-1}\)) with the ‘individual endurance’ athletes having a higher peak oxygen uptake (ml. kg\(^{-1}\).min\(^{-1}\)) (P<0.01) than any of the other subsets of the elite athletes. Krahenbuhl et al., (1985), in a review of studies looking at maximal aerobic power in children, ages ranging from 4 years old to 16 years old, found that aerobic power (VO\(_2\) max) in trained and untrained males and females has been shown to increase with chronological age, with the values for the trained subjects being higher at all ages, a finding confirmed in the current study when peak VO\(_2\) was expressed in l.min\(^{-1}\). Endurance exercise training is known to produce an increase in left ventricular size of the heart, which increases stroke volume leading to a reduced heart rate during submaximal exercise but not during maximal exercise (Spina, 1999). When exercising maximally the larger cardiac output and increased extraction of oxygen from the blood by the exercising muscle leads to a higher peak VO\(_2\) (Jones and Carter, 2000b). Maximal oxygen uptake in exercising humans is limited by the ability of the cardiorespiratory system to deliver oxygen to the exercising muscles (Bassett and Howley, 2000). Åstrand and Saltin (1961) found that despite repeated attempts, efforts to drive the oxygen uptake to higher levels by increasing the work rate were ineffective. Each successive attempt resulted in an increase in the rate of climb in VO\(_2\) but the upper level reached is about the same in each case. This finding had been predicted by Hill and Lupton in 1923 (op. cit Bassett and Howley, 2000) who theorised that there is an upper limit to oxygen uptake and this will be different for each individual. Thus, an individual’s running ability may be largely dependent on their ability to utilise oxygen.

Bassett and Howley (2000), identify four limiting factors for maximal oxygen uptake. The three central factors are 1) pulmonary diffusing capacity, 2) maximal cardiac output.
and, 3) the oxygen carrying capacity of the blood. The last, peripheral factor, is 4) skeletal muscle characteristics.

1) Pulmonary diffusing capacity refers to the ability of the lungs to saturate arterial blood with oxygen. At sea level, the average individual exercising at maximum will have an arterial blood saturation of around 95% (Powers et al., 1989). Trained individuals are likely to have a much higher cardiac output than their untrained peers (Bassett and Howley, 2000), leading to a decrease in the time that the red blood cells spend in the pulmonary capillary which may result in the blood being unable to be saturated with oxygen before it leaves the pulmonary capillary (Bassett and Howley, 2000).

2) In 1923 Hill et al. (op. cit. Bassett and Howley, 2000) posited that the primary factor that explained individual differences in \( \dot{V}O_2 \max \) was maximal cardiac output i.e. highly trained endurance athletes have hearts with superior pumping capacities. This theory was supported when Saltin et al., (1968), in a classic study, investigated \( \dot{V}O_2 \max \) in sedentary individuals after 20 days bed rest and then 50 days of training. The investigators found that the differences in \( \dot{V}O_2 \max \) between the two states resulted mostly from a difference in cardiac output (Saltin et al., 1968).

3) The third factor that has been shown to limit maximal oxygen uptake is the oxygen carrying capacity of the blood. Thus if the haemoglobin (Hb) content of the blood is altered the oxygen transport to the exercising muscles will also be altered. This is clearly demonstrated by the practice of blood doping which is used (illegally) in some sports to gain competitive advantage. Blood doping is where the volume of total red blood cells in an individual is artificially increased through removal, storage, and later re-infusion (Gledhill, 1982, 1985). \( \dot{V}O_2 \max \) has been shown to increase by 4-9% when re-infusion of 900 – 1350 mL of blood has taken place in double blind trials, thus providing evidence of the oxygen carrying capacity of the blood and of the cause and effect link between oxygen delivery and \( \dot{V}O_2 \max \) (Gledhill, 1982, 1985).

4) Limitations of the skeletal muscle is the fourth factor that may affect maximal oxygen uptake. Within the muscle fibres the mitochondria are the sites where oxygen is consumed (Bassett and Howley, 2000). The increase in muscle mitochondria that comes about through training may allow for a slightly greater
amount of oxygen to be extracted from the blood by the exercising muscle, thus having a minor contribution to an increased \( \dot{V}O_2 \text{ max} \) (Holloszy and Coyle, 1984).

The elite athletes are less economical \((P<0.01)\) when performing the submaximal incremental treadmill running test than the non-elite athletes, a finding that confirms that of Van Huss et al. (1988) who found that the elite female runners in their trial of runners aged 9 – 15 years old, had consistently higher oxygen uptakes during running than did the female control runners; however there was no effect of maturation in this study. Conversely, Morgan et al., (1995) found in a retrospective analysis of seven published studies looking at the differences in ‘aerobic demand’ of running in a large group \((n=89)\) of trained and untrained subjects, that elite runners display better economy compared to less talented counterparts. However, Morgan et al. (1995) also found that economical and uneconomical runners can be found in all performance categories and suggested that variability in running economy within a particular cohort was independent of performance ability, training status or familiarity with running (Morgan et al., 1995) which may, in part, explain why the elite athletes in the present study were less economical than the non-elite athletes, as only nine members of the elite cohort were distance runners.

In the present study blood lactate concentration during submaximal running was significantly lower in the elite athletes, which was also reported by Van Huss (1988) and by Hemmings (2006 Unpublished Thesis). The lower blood lactate concentration of the elite athletes was probably due to lower relative exercise intensities as supported by the significantly lower heart rates and rates of perceived exertion that they showed. Other variables measured during the submaximal treadmill running test also reflect a lower relative exercise intensity with heart rate, rate of perceived exertion, and R value all being lower in elite than non-elite athletes. However, it is not clear why the elite athletes should be less economical than the non-elite athletes in the present study. There are a number of factors that might account for this; the elite athletes were heavier than the non-elite athletes and therefore could have been hampered by having to move a greater body mass. However, the elite athletes had significantly lower sum of four skinfolds, indicating a higher percentage of fat free mass, namely muscle, which would be active in supporting the higher body mass and aiding more effective and faster
locomotion. Another confounding factor may be that the elite athletes found the slower speeds at the beginning of the run uncomfortably slow and thus they were unable to perform as effectively as they would normally; the treadmill speeds had to be set lower at the start of the test to enable the non-elite athletes to participate effectively.

The results of the elite athletes in this study were broken down into one of four subsets depending on the sport type that the athletes participated in; ‘team players’, ‘individual endurance’ athletes, ‘individual games players’, and ‘individual other’ athletes. When data for the elite subsets were examined it was found that the elite endurance athletes were lighter than the other elite groups and had less body fat (see chapter 4, Table 4.7-4.10). However, when the submaximal incremental treadmill running data for oxygen uptake (ml.kg\(^{-1}\).min\(^{-1}\)) was analysed there were no differences between any of the elite subsets. The elite endurance athletes had lower blood lactate concentrations (mmol.l\(^{-1}\)) than two of the other subsets of elite athletes (‘team players’ and the ‘individual other’ group) suggesting that they were running at a much lower relative exercise intensity in comparison with these other subsets when performing the submaximal incremental treadmill run. This pattern of results was repeated for heart rate, percentage of maximum heart rate, and R value. In addition the lower blood lactate concentration possibly reflects the enhanced endurance training status of the ‘individual endurance’ group, whereby their physiological responses would be lower even at the same relative exercise intensity.

There has been very little research comparing elite female adolescent athletes with non-elite female adolescent athletes and much of the current understanding of the physiological responses to training/exercise in adolescent girls has been extrapolated from that for boys and/or adults. Due to their progress through the various stages of maturation it is important that adolescent females are not compared physiologically with women who are fully sexually mature, or with pre-pubertal females. Maturational stage in this study was taken from the pubic hair stage. Maturation was not a significant factor in the uptake of oxygen or blood lactate concentrations during submaximal running, between the elite and non-elite athletes although there was interaction of group x age (P<0.05) when analysing oxygen uptake (ml.kg\(^{-1}\).min\(^{-1}\)) during submaximal running.
In conclusion, the elite female athletes had higher peak oxygen uptakes (l.min$^{-1}$), lower maximum heart rates (beats.min$^{-1}$) than the non-elite females, with a main effect of maturation and age so that as the athletes grew older and progressed in their sexual maturation peak $\dot{V}O_2$ (l.min$^{-1}$) increased. When peak oxygen uptake was scaled by body mass (ml.kg$^{-1}$.min$^{-1}$) the elite athletes still had higher peak $\dot{V}O_2$ than the non-elite athletes but there was no longer an effect of maturation or age. $\dot{V}O_2$ is known to increase with chronological age, for both trained and untrained subjects, but with the trained subjects having higher values than the untrained subjects at all ages (Krahenbuhl et al., 1985). Similarly it is known that maximum heart rate may be affected by training which can increase left ventricular size of the heart, thereby increasing stroke volume which leads to a reduced heart rate during submaximal exercise. The elite female adolescent athletes in this study were not as economical as their non-elite counterparts yet had lower lactate production (mmol.l$^{-1}$), lower heart rate (beats.min$^{-1}$), worked at a lower percentage of their maximum heart rates, reporting lower rates of perceived exertion and had lower R Values than the non-elite athletes. This suggests that the elite athletes were working at lower intensities throughout the test but does not explain why they were less efficient. The reasons for this may be due to uneven gait (something which seems unlikely in elite well trained athletes), or may be something as simple as the fact that the elite athletes found that running at initially low speeds on the treadmill difficult, or that the majority of the elite athletes were not distance runners and generally took part in sports where intermittent running was the norm.
Chapter 6

30 s Maximal Cycle Ergometer Sprinting and Strength in Elite and Non-Elite Female Adolescent Athletes

6.1 Introduction

Short high intensity bursts of movement lasting just a few seconds are the most common type of exercise seen in young people when going about their daily lives, at school, at home and during leisure and sporting activities (Bailey et al., 1995b). Although this is the case, there has been very little research examining this type of activity in young people during growth and maturation, with researchers concentrating on the development of oxygen uptake. Several reasons have been suggested for this lack of research, including ethical considerations prohibiting highly invasive, painful and stressful measurement techniques when studying healthy children (Van Praagh, 2000). However, whether or not such comments could apply to cycle ergometer sprinting and finger prick blood sampling is questionable. More likely, methodological issues are a major concern in this area.

The measurement of short-term muscle power can be determined using a variety of tests; vertical jump, sprint running, cycle and rowing ergometry. Peak power can be defined as the highest mechanical power that can be delivered in exercise of up to 30 seconds duration (Van Praagh and Doré, 2002). Power is the product of force and velocity; the force generated by a muscle is related to the cross-sectional area of the active muscle, the velocity of the contraction of the muscle relates to the length of the muscle fibre (Martin and Malina, 1998). Muscle power has been defined by Van Praagh and Doré (2002) as being the ability of the neuromuscular system to produce the highest possible impulse in a given period of time.

One of the tests commonly used for the measurement of short-term muscle power in young people is a 30 second maximal cycle sprint using the method described by Lakomy (1986), which takes into account the flywheel inertia and thus provides ‘true’ maximal power values. This test allows the researcher to determine the cycling peak
power output (W) in a period of one to five seconds and the mean power output (W) over the course of thirty seconds. Measures are recorded in both absolute (Watts) and ratio scaled terms (W.kg\(^{-1}\)) in order to account for the differences in body mass of the participants. There are researchers who question whether simple ratio-scaling is enough to account for the differential between participants, particularly as participants in cycle ergometry are weight supported which isolates activity to the legs. Some researchers (Armstrong et al., 1997; Armstrong et al., 2001; Döré et al., 2005) use allometric scaling using measures such as lean leg volume, total leg volume, sum of two skinfolds, and fat free mass as additional factors with which to more finely define the measures taken.

Whichever method of analysis is used, absolute, ratio-scaled or allometric scaling, peak power output has been shown to increase with age. Armstrong et al. (1997, 2000, 2001) have shown that whilst maturation did not affect the development of peak power, body mass and skinfold thickness are significant influences on both peak power output and mean power output.

Döré et al. (2005) investigated sex related differences in maximal leg muscle power in a large cohort of females (796) and males (426) aged between 8 and 20 years old. They found that for a similar lean leg volume (assessed by anthropometry) the males showed a greater cycling peak power than the females from the age of 14 years onwards. The difference in peak power between males and females was probably due to an increase in body fat (particularly lower body fat) in the girls during puberty, whilst the boys experienced an increase in lean leg volume.

High intensity exercise has been shown to induce a rise in blood lactate concentration (Williams et al., 1997), both in adults and children, but blood lactate concentrations are lower in children than in adults. Williams et al. (1994) investigated the relationship between sexual maturation and blood lactate concentration following cycle ergometer sprinting. 97 boys (12.3±0.3 y) and 88 girls (12.5±0.4 y) performed a 30 cycle ergometer sprint. No significant main effects of sex or maturity for post-exercise blood lactate concentrations (P<0.05) were revealed. Some researchers have found lactate levels for children that approach those of adult values. There is a dearth of literature that examines peak power in girls and even less examining the peak power and
metabolic responses to 30 s cycle ergometer sprinting for elite in comparison with non-elite female adolescent athletes.

Very few studies have investigated the muscle strength of adolescent girls. Due to ethical constraints there have been few studies that have examined the muscle structure and function of young people, though with the development of magnetic resonance imaging and Dual-energy X-ray absorptiometry techniques this is changing (Armstrong and Welsman, 1997; Malina et al., 2004b). The maximal force that can be generated by an adult skeletal muscle is mainly a function of the muscle size and neural control over the force generation (Malina et al., 2004b). As muscle strength is highly dependent on muscle size the sex differences in the development of muscle mass may account for much of the observed age and sex related differences in muscle strength (Armstrong and Welsman, 1997; Malina et al., 2004b). There is evidence that the upper and lower body show different patterns of muscle development and growth during adolescence (Round et al., 1999), with boys being found to have greater gains in strength at and after peak height velocity.

Round et al. (1999) investigated the development of elbow flexor (biceps) and knee extensor (quadriceps) strength in a mixed longitudinal study of 50 boys and 50 girls from the age of 8 years to 17 years. The children were measured 3 times a year and growth curves were constructed for each child. Peak height velocity was calculated, maturation stages were assessed using the Tanner scales (Tanner, 1978). Muscle strength (maximal voluntary contraction) of the quadriceps and biceps was measured. Multi-level modelling was used to analyse the results. Increases in strength were shown to be similar between boys and girls until about 1 year before peak height velocity. In both muscle groups, thereafter, clear differences between the sexes were evident in the rate of increase in strength from 0 to 2 years after peak height velocity. The results showed that for girls, development of quadriceps strength is proportional to the increase in height and weight. In contrast, the girls' bicep strength appeared to become weaker with age, relative to changes in body size (Round et al., 1999). There is a paucity of literature available examining research into the strength of elite and non-elite female adolescent athletes.
Thus the purpose of the present study is to test the hypothesis that the elite female adolescent athletes will have higher peak power and mean power outputs together with higher blood lactate responses to a 30 second WAnT sprint test when compared by age and by maturity and will examine the hypothesis that elite female adolescent athletes have greater muscle strength when tested on a Concept2 Dyno® than non-elite female adolescent athletes. Also, for the first time this study will also examine power output, metabolic responses and muscle strength of elite female athletes in different sporting sub-groups when tested on a Concept2 Dyno®.

6.2 Methods

6.2.1 Participants
Eighty six elite and 100 non-elite adolescent females of between 12 and 17 years of age volunteered to take part in the study. The elite performers either attended summer performance camps with their respective national training squads at the time of testing or were participating in studies which recruited by selection from specialist sports schools and colleges in the counties of Nottinghamshire, Leicestershire and Derbyshire. The non-elite participants were recruited from schools local to Loughborough and also from the specialist sports schools and colleges mentioned above. Written informed consent and assent was sought prior to involvement by parent/guardian and/or caregiver and participant respectively, for the studies, which were approved by Loughborough University Ethical Committee. A more detailed description can be seen in Chapter 3, General Methods.

6.2.2 Physical Characteristics
Stature was measured to the nearest 0.1 cm and body mass to the nearest 0.1 kg. Participants were dressed in t-shirts and shorts without shoes. Skinfold thickness for the determination of body fatness was measured at the following sites using a Harpenden calliper: tricep, bicep, subscapular and supraspinale (Norton et al., 1996). The mean value of the measurements was summed to give the skinfold measurement as the sum of four skinfolds. For a more detailed account of the method of skinfold measurement please refer to Chapter 3, General Methods. Age was calculated from the date of birth
and the date of the test. All participants were asked to perform a self-assessment of maturity by assessing their secondary sexual characteristics according to Tanner's (1962) indices of secondary sex characteristics. A more detailed account of the procedure can be seen in Chapter 3, General Methods.

Before performing the test each participant was familiarised with the 30 s Maximal Cycle Ergometer Sprint procedure as detailed in Chapter 3, General Methods. Briefly, all participants completed a standardised warm-up consisting of cycling for 30 s at 80 rev.min⁻¹, followed by 30 s rest and then a further 30 s cycling at 110 rev.min⁻¹, all against 1 kg resistive mass. Five minutes after completion of the warm-up the participants performed a maximal 30 s cycle sprint from a rolling start of 60 rev.min⁻¹ against a resistive mass of 0.07 kg.kg⁻¹ body mass. Strong verbal encouragement was given throughout the duration of the test. The power output was calculated for each second of the duration of the test. The peak power over one second and the mean power over the whole 30 s period were recorded. Fatigue index was also calculated from the difference in peak power and the lowest power output value (100 / peak power output x lowest power output). All procedures were undertaken as described by Lakomy (1982).

6.2.3 Blood lactate sampling and analysis

A resting finger-prick capillary blood sample was collected before the commencement of the test for the determination of blood lactate concentration by a fluorometric method (Maughan, 1982). For a more detailed account of this procedure please see Chapter 3, General Methods. Finger-tip capillary blood samples were also collected at 3 min post warm-up and at 2 min and 5 min post-sprint.

6.2.4 Statistical analysis

Descriptive statistics for physical characteristics were calculated for elite and non-elite groups by age and maturational stage. Two-way (age x group) and (maturity x group) analysis of variance (ANOVA) were used to determine the relationship between peak and mean power outputs both in absolute (W) terms and by body mass (expressed per kg¹.⁰ body mass) and also by lean Body Mass (W.kg⁻¹). Results are expressed as mean ± standard error of the mean.
6.3 Results

6.3.1 Physical characteristics

The descriptive physical characteristics of the elite and non-elite adolescent female sports performers aged 12 – 17 years who participated in the study analysed by age and maturation status are presented in Chapter 4, Tables 4.1 - 4.10.
6.3.2 30 second maximal cycle sprint

6.3.2.1 Peak Power
There was a main effect of age $P<0.01$ when peak power output (W) during the 30 second maximal cycle sprint was analysed, with the older girls recording higher peak power outputs (W) than the younger girls; there was an interaction of age x group $P<0.01$ with the older elite athletes recording higher peak power outputs (W) than the older non-elite athletes. When peak power output (W.kg$^{-1}$) was analysed by age there were no differences between the elite and non-elite athletes, however there was an interaction of age x group $P<0.01$ with the older elite athletes recording higher peak power outputs (W.kg$^{-1}$) than the non-elite athletes. [Table 6.1]

Table 6.1 Peak power output (W) and (W.kg$^{-1}$) for elite and non-elite adolescent female sports performers by age (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Age</th>
<th>Elite Watts</th>
<th>Non-Elite Watts</th>
<th>Elite W.kg$^{-1}$</th>
<th>Non-Elite W.kg$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 years</td>
<td>349±40</td>
<td>419±24</td>
<td>8.64±0.75</td>
<td>8.80±0.52</td>
</tr>
<tr>
<td>(n)</td>
<td>(6)</td>
<td>(11)</td>
<td>(6)</td>
<td>(11)</td>
</tr>
<tr>
<td>13 years</td>
<td>406±24</td>
<td>476±22</td>
<td>7.97±0.40</td>
<td>8.71±0.40</td>
</tr>
<tr>
<td>(n)</td>
<td>(13)</td>
<td>(23)</td>
<td>(13)</td>
<td>(23)</td>
</tr>
<tr>
<td>14 years</td>
<td>478±21</td>
<td>468±28</td>
<td>8.34±0.25</td>
<td>8.19±0.33</td>
</tr>
<tr>
<td>(n)</td>
<td>(20)</td>
<td>(19)</td>
<td>(20)</td>
<td>(19)</td>
</tr>
<tr>
<td>15 years</td>
<td>513±19</td>
<td>450±19</td>
<td>8.99±0.27</td>
<td>8.03±0.36</td>
</tr>
<tr>
<td>(n)</td>
<td>(18)</td>
<td>(27)</td>
<td>(18)</td>
<td>(27)</td>
</tr>
<tr>
<td>16 years</td>
<td>612±25</td>
<td>457±33</td>
<td>9.67±0.32</td>
<td>7.66±0.33</td>
</tr>
<tr>
<td>(n)</td>
<td>(11)</td>
<td>(8)</td>
<td>(11)</td>
<td>(8)</td>
</tr>
</tbody>
</table>

NS Group
Main Effect Age $P<0.01$
Age x Group $P<0.01$
Peak power increased with maturation stage \((P<0.01)\), with the females who recorded higher maturation scores having higher peak power outputs \((W)\). When peak power output \((W.kg^{-1})\) was analysed by maturation status there were no differences between the elite and non-elite female adolescent athletes. [Table 6.2]

**Table 6.2** Peak power output \((W)\) and \((W.kg^{-1})\) for elite and non-elite adolescent female sports performers by Tanner stage \((PH)\) (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th></th>
<th>Elite</th>
<th>Non-Elite</th>
<th>Elite</th>
<th>Non-Elite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Watts</td>
<td></td>
<td>Watts</td>
<td></td>
</tr>
<tr>
<td></td>
<td>365±29</td>
<td>378±26</td>
<td>8.10±0.57</td>
<td>8.76±0.74</td>
</tr>
<tr>
<td>Tanner Stage 2 (PH)</td>
<td>(11)</td>
<td>(7)</td>
<td>(11)</td>
<td>(7)</td>
</tr>
<tr>
<td>Tanner Stage 3 (PH)</td>
<td>459±30</td>
<td>452±29</td>
<td>8.55±0.38</td>
<td>8.72±0.37</td>
</tr>
<tr>
<td></td>
<td>(16)</td>
<td>(14)</td>
<td>(16)</td>
<td>(14)</td>
</tr>
<tr>
<td>Tanner Stage 4 (PH)</td>
<td>489±20</td>
<td>452±16</td>
<td>8.60±0.24</td>
<td>7.92±0.27</td>
</tr>
<tr>
<td></td>
<td>(21)</td>
<td>(17)</td>
<td>(21)</td>
<td>(17)</td>
</tr>
<tr>
<td>Tanner Stage 5 (PH)</td>
<td>555±25</td>
<td>490±21</td>
<td>9.16±0.37</td>
<td>8.33±0.33</td>
</tr>
<tr>
<td></td>
<td>(17)</td>
<td>(28)</td>
<td>(17)</td>
<td>(28)</td>
</tr>
</tbody>
</table>

NS Group

Main Effect Maturation \(P<0.01\)
Mean power (W) and (W.kg\(^{-1}\)) was higher in the elite than the non-elite athletes (main effect of group P<0.01). Mean power (W) increased with age in both groups (main effect age P<0.01) There was an interaction of age x group (P<0.01) with the older elite athletes recording higher mean power outputs (W) and (W.kg\(^{-1}\)) than the non-elite athletes. [Table 6.3]

**Table 6.3** Mean power output (W) and (W.kg\(^{-1}\)) for elite and non-elite adolescent female sports performers by age (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th></th>
<th>Elite Watts</th>
<th>Non-Elite Watts</th>
<th>Elite W.kg(^{-1})</th>
<th>Non-Elite W.kg(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 years</td>
<td>249±19 (6)</td>
<td>276±16 (11)</td>
<td>6.19±0.31 (6)</td>
<td>5.73±0.29 (11)</td>
</tr>
<tr>
<td>13 years</td>
<td>274±12 (13)</td>
<td>326±14 (20)</td>
<td>5.40±0.26 (13)</td>
<td>5.94±0.18 (20)</td>
</tr>
<tr>
<td>14 years</td>
<td>349±12 (21)</td>
<td>319±16 (21)</td>
<td>6.12±0.15 (21)</td>
<td>5.60±0.19 (21)</td>
</tr>
<tr>
<td>15 years</td>
<td>376±12 (20)</td>
<td>299±13 (28)</td>
<td>6.59±0.18 (20)</td>
<td>5.33±0.23 (28)</td>
</tr>
<tr>
<td>16 years</td>
<td>422±13 (19)</td>
<td>312±19 (12)</td>
<td>6.66±0.15 (19)</td>
<td>5.26±0.23 (12)</td>
</tr>
</tbody>
</table>

Main Effect Group P<0.01
Main Effect Age P<0.01
Age x Group P<0.01
There was a main effect of group $P<0.01$ when mean power output (W) of the 30 second maximal cycle sprint was analysed with the elite athletes having a higher mean power output (W) than the non-elite athletes, there was also an main effect of maturation $P<0.01$ with the more mature females having a higher mean power output (W) than the less mature females. When mean power output (W.kg$^{-1}$) was analysed by maturation stage there was a main effect of group $P<0.01$ with the elite athletes having a higher mean power output (W.kg$^{-1}$) than the non-elite athletes. [Table 6.4]

Table 6.4  Mean power output (W) and (W.kg$^{-1}$) for elite and non-elite adolescent female sports performers by Tanner stage (PH) (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Tanner Stage 2 (PH)</th>
<th>Elite Watts &amp; Non-Elite Watts</th>
<th>Elite W.kg$^{-1}$ &amp; Non-Elite W.kg$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(n)</td>
<td>252±14 &amp; 240±19</td>
<td>5.64±0.32 &amp; 5.52±0.46</td>
</tr>
<tr>
<td>(n)</td>
<td>(11) &amp; (7)</td>
<td>(11) &amp; (7)</td>
</tr>
<tr>
<td>Tanner Stage 3 (PH)</td>
<td>328±18 &amp; 294±15</td>
<td>6.12±0.19 &amp; 5.72±0.20</td>
</tr>
<tr>
<td>(n)</td>
<td>(16) &amp; (14)</td>
<td>(16) &amp; (14)</td>
</tr>
<tr>
<td>Tanner Stage 4 (PH)</td>
<td>353±14 &amp; 317±11</td>
<td>6.21±0.17 &amp; 5.55±0.16</td>
</tr>
<tr>
<td>(n)</td>
<td>(21) &amp; (40)</td>
<td>(21) &amp; (40)</td>
</tr>
<tr>
<td>Tanner Stage 5 (PH)</td>
<td>378±10 &amp; 324±13</td>
<td>6.25±0.11 &amp; 5.50±0.19</td>
</tr>
<tr>
<td>(n)</td>
<td>(17) &amp; (28)</td>
<td>(17) &amp; (28)</td>
</tr>
</tbody>
</table>

Main Effect Group $P<0.01$

Main Effect Maturation $P<0.01$
When peak power output (W.kg\(^{-1}\)) was analysed by lean body mass there were no differences between the elite and non-elite athletes when analysed by age, however there was an interaction of age x group \(P<0.05\) showing that the older elite athletes had higher peak power outputs (W.kg\(^{-1}\)) than the non-elite athletes. When mean power output (W.kg\(^{-1}\)) was analysed by lean body mass there was a tendency towards a main effect of group \((P=0.078)\) between the elite and non-elite athletes with the elite athletes more likely to record higher mean power output scores than the non-elite athletes. There was a main effect of age \((P<0.05)\) with the older athletes having higher mean power outputs (W.kg\(^{-1}\)) by lean body mass than the younger athletes. There was an interaction of age x group with the older elite athletes having higher mean power output (W.kg\(^{-1}\)) by lean body mass than the non-elite athletes \((P<0.01)\). [Table 6.5]

Table 6.5  
Peak power output (PPO) and mean power output (MPO) by lean body mass (LBM) (W.kg\(^{-1}\)) for elite and non-elite adolescent female sports performers by age (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Age</th>
<th>PPO by LBM</th>
<th>MPO by LBM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Elite W.kg(^{-1})</td>
<td>Non-Elite W.kg(^{-1})</td>
</tr>
<tr>
<td>12 years</td>
<td>10.59±0.86 (6)</td>
<td>11.55±0.59 (11)</td>
</tr>
<tr>
<td>13 years</td>
<td>10.66±0.59 (11)</td>
<td>12.02±0.48 (20)</td>
</tr>
<tr>
<td>14 years</td>
<td>11.20±0.35 (20)</td>
<td>12.03±0.46 (18)</td>
</tr>
<tr>
<td>15 years</td>
<td>12.01±0.44 (24)</td>
<td>11.89±0.55 (15)</td>
</tr>
<tr>
<td>16 years</td>
<td>13.50±0.72 (9)</td>
<td>10.96±0.43 (8)</td>
</tr>
</tbody>
</table>

*NS Group Main Effect Group \(P=0.078\)*

*Age x Group \(P<0.05\) Main Effect Age \(P<0.05\)*

*Age x Group \(P<0.01\)*
When peak power output (W.kg\(^{-1}\)) and mean power output (W.kg\(^{-1}\)) were analysed by lean body mass there were no differences between the elite and non-elite athletes when compared by maturation status. [Table 6.6]

Table 6.6  Peak power output (PPO) and mean power output (MPO) by lean body mass (LBM) (W.kg\(^{-1}\)) for elite and non-elite adolescent female sports performers by Tanner stage (PH) (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Tanner Stage</th>
<th>Elite PPO by LBM (W.kg(^{-1}))</th>
<th>Non-Elite PPO by LBM (W.kg(^{-1}))</th>
<th>Elite MPO by LBM (W.kg(^{-1}))</th>
<th>Non-Elite MPO by LBM (W.kg(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 (PH)</td>
<td>10.35±0.62 (11)</td>
<td>12.48±0.78 (5)</td>
<td>7.19±0.29 (11)</td>
<td>7.73±0.55 (5)</td>
</tr>
<tr>
<td>3 (PH)</td>
<td>11.16±0.78 (12)</td>
<td>11.86±0.57 (13)</td>
<td>8.36±0.47 (12)</td>
<td>7.83±0.27 (13)</td>
</tr>
<tr>
<td>4 (PH)</td>
<td>11.71±0.36 (19)</td>
<td>11.54±0.38 (35)</td>
<td>8.60±0.20 (19)</td>
<td>8.13±0.22 (35)</td>
</tr>
<tr>
<td>5 (PH)</td>
<td>12.26±0.45 (15)</td>
<td>12.10±0.45 (25)</td>
<td>8.54±0.18 (15)</td>
<td>8.02±0.25 (25)</td>
</tr>
</tbody>
</table>

NS Group

NS Group
When the fatigue responses were analysed by by age and maturation status there was a main effect of group $P<0.01$ with the elite athletes tiring less than the non-elite athletes. 

[Table 6.7 and Table 6.8 ]

**Table 6.7** Fatigue responses to a 30 second maximal bicycle sprint for elite and non-elite adolescent female sports performers by age (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Fatigue Rate - Percentage Drop</th>
<th>Elite</th>
<th>Non-Elite</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>12 years</strong></td>
<td>50.7±2.3</td>
<td>60.3±3.0</td>
</tr>
<tr>
<td>(n)</td>
<td>(6)</td>
<td>(11)</td>
</tr>
<tr>
<td><strong>13 years</strong></td>
<td>59.2±4.6</td>
<td>56.0±2.7</td>
</tr>
<tr>
<td>(n)</td>
<td>(13)</td>
<td>(20)</td>
</tr>
<tr>
<td><strong>14 years</strong></td>
<td>49.7±2.4</td>
<td>55.3±2.0</td>
</tr>
<tr>
<td>(n)</td>
<td>(20)</td>
<td>(21)</td>
</tr>
<tr>
<td><strong>15 years</strong></td>
<td>47.8±3.0</td>
<td>60.5±2.7</td>
</tr>
<tr>
<td>(n)</td>
<td>(20)</td>
<td>(28)</td>
</tr>
<tr>
<td><strong>16 years</strong></td>
<td>53.0±2.2</td>
<td>57.6±4.5</td>
</tr>
<tr>
<td>(n)</td>
<td>(18)</td>
<td>(13)</td>
</tr>
</tbody>
</table>

Main Effect Group $P<0.01$

**Table 6.8** Fatigue responses to a 30 second maximal bicycle sprint for elite and non-elite adolescent female sports performers by Tanner stage (PH) (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Fatigue Rate - Percentage Drop</th>
<th>Elite</th>
<th>Non-Elite</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tanner Stage 2 (PH)</strong></td>
<td>56.5±5.1</td>
<td>61.5±2.6</td>
</tr>
<tr>
<td>(n)</td>
<td>(11)</td>
<td>(7)</td>
</tr>
<tr>
<td><strong>Tanner Stage 3 (PH)</strong></td>
<td>49.1±3.0</td>
<td>63.2±3.0</td>
</tr>
<tr>
<td>(n)</td>
<td>(16)</td>
<td>(14)</td>
</tr>
<tr>
<td><strong>Tanner Stage 4 (PH)</strong></td>
<td>51.0±2.8</td>
<td>55.6±2.3</td>
</tr>
<tr>
<td>(n)</td>
<td>(20)</td>
<td>(40)</td>
</tr>
<tr>
<td><strong>Tanner Stage 5 (PH)</strong></td>
<td>51.4±2.5</td>
<td>57.6±2.0</td>
</tr>
<tr>
<td>(n)</td>
<td>(16)</td>
<td>(28)</td>
</tr>
</tbody>
</table>

Main Effect Group $P<0.01$
Blood lactate (mmol\(^{-1}\)) responses to the 30 second maximal cycle sprint, when analysed by age showed a main effect of group at post warm-up stage, with the elite athletes having lower blood lactate values than the non-elite athletes (P<0.01). There was no effect of group at the 2 minutes post-sprint stage, though there was a main effect of age with the older athletes having higher blood lactate (mmol\(^{-1}\)) values than the younger athletes (P<0.01). There was an interaction of age x group (P<0.05) with the older elite athletes having higher blood lactate values (mmol\(^{-1}\)) than the younger elite athletes. When the blood lactate (mmol\(^{-1}\)) values at 5 minutes post-sprint were analysed there was no effect of group though there was a main effect of age (P<0.01), with the older athletes having higher blood lactate (mmol\(^{-1}\)) values than the younger athletes. [Table 6.9]

Table 6.9  Post warm-up, 2 min post-sprint and 5 min post-sprint blood lactate responses (mmol.l\(^{-1}\)) to a 30 second maximal bicycle sprint for elite and non-elite adolescent female sports performers by age (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Age</th>
<th>Elite Post Warm-up</th>
<th>Non-Elite 30 s Maximal Cycle Sprints and Strength</th>
<th>Elite 2 min post Sprint</th>
<th>Non-Elite 2 min post Sprint</th>
<th>Elite 5 min post Sprint</th>
<th>Non-Elite 5 min post Sprint</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 years</td>
<td>4.0±0.4 (5)</td>
<td>3.0±0.1 (10)</td>
<td>7.2±0.1 (6)</td>
<td>7.1±0.7 (9)</td>
<td>7.0±0.4 (6)</td>
<td>7.1±0.9 (8)</td>
</tr>
<tr>
<td>13 years</td>
<td>2.4±0.2 (12)</td>
<td>3.3±0.3 (22)</td>
<td>7.1±0.5 (12)</td>
<td>8.2±0.3 (22)</td>
<td>6.8±0.6 (12)</td>
<td>8.1±0.5 (21)</td>
</tr>
<tr>
<td>14 years</td>
<td>2.1±0.2 (21)</td>
<td>3.4±0.4 (20)</td>
<td>7.3±0.3 (21)</td>
<td>8.5±0.2 (20)</td>
<td>7.3±0.5 (20)</td>
<td>8.4±0.4 (20)</td>
</tr>
<tr>
<td>15 years</td>
<td>2.6±0.3 (21)</td>
<td>3.9±0.4 (30)</td>
<td>8.9±0.5 (21)</td>
<td>8.3±0.4 (30)</td>
<td>8.6±0.5 (20)</td>
<td>8.5±0.3 (27)</td>
</tr>
<tr>
<td>16 years</td>
<td>2.5±0.3 (17)</td>
<td>3.4±0.3 (13)</td>
<td>9.5±0.3 (19)</td>
<td>8.7±0.5 (12)</td>
<td>10.3±0.6 (18)</td>
<td>9.4±0.4 (13)</td>
</tr>
</tbody>
</table>

Main Effect Group

P<0.01

Main Effect Age

P<0.01

Age x Group P<0.05

NS Group

NS Group

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Blood lactate (mmol.l⁻¹) responses to the 30 second maximal cycle sprint, when analysed by maturation status showed a main effect of group (P<0.01) at post warm-up stage, with the elite athletes having lower lactate values than the non-elite athletes. There was no effect of group at the 2 minutes post-sprint stage, though there was a main effect of maturation P=0.055 with the athletes who recorded a higher maturation score having a tendency to have higher lactate (mmol-1) values than the athletes with a lower maturation score. When blood lactate (mmol.l⁻¹) values at 5 minutes post-sprint were analysed there was no effect of group though there was a main effect of maturation P<0.05, with the athletes who scored themselves higher for maturation having higher blood lactate (mmol.l⁻¹) values than the less mature athletes. [Table 6.9]

Table 6.10 Post warm-up, 2 min post-sprint and 5 min post-sprint lactate responses (mmol.l⁻¹) to a 30 second maximal bicycle sprint for elite and non-elite adolescent female sports performers by Tanner stage (PH) (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Tanner Stage</th>
<th>Elite Post warm-up (mmol⁻¹)</th>
<th>Non-Elite Post warm-up (mmol⁻¹)</th>
<th>Elite 2 min post-sprint (mmol⁻¹)</th>
<th>Non-Elite 2 min post-sprint (mmol⁻¹)</th>
<th>Elite 5 min post-sprint (mmol⁻¹)</th>
<th>Non-Elite 5 min post-sprint (mmol⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 (PH)</td>
<td>3.1±0.4 (11)</td>
<td>4.2±0.6 (7)</td>
<td>6.8±0.5 (10)</td>
<td>7.9±0.8 (70)</td>
<td>6.8±0.7 (11)</td>
<td>7.1±1.1 (7)</td>
</tr>
<tr>
<td>3 (PH)</td>
<td>2.5±0.2 (14)</td>
<td>3.1±0.3 (16)</td>
<td>7.7±0.3 (15)</td>
<td>7.6±0.5 (16)</td>
<td>7.8±0.4 (14)</td>
<td>8.0±0.5 (15)</td>
</tr>
<tr>
<td>4 (PH)</td>
<td>2.5±0.3 (20)</td>
<td>3.6±0.3 (40)</td>
<td>8.0±0.6 (21)</td>
<td>8.6±0.3 (39)</td>
<td>7.5±0.6 (20)</td>
<td>8.6±0.2 (37)</td>
</tr>
<tr>
<td>5 (PH)</td>
<td>2.4±0.2 (17)</td>
<td>3.6±0.3 (30)</td>
<td>8.5±0.3 (18)</td>
<td>8.5±0.3 (29)</td>
<td>8.6±0.5 (16)</td>
<td>8.8±0.3 (29)</td>
</tr>
</tbody>
</table>

Main Effect Group
P<0.01

NS Group
Main Effect
Maturation P=0.055
Main Effect
Maturation P<0.05

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6.3.2 Strength measurements

The analysis by age of the leg strength measures performed on a Concept2 Dyno® by elite and non-elite athletes no effect of group for the combined leg press. There was a main effect of age for all three of the leg press exercises with the older girls able to press greater loads than the younger girls (P<0.01). There was an interaction of age x group with the older elite athletes able to press greater loads than the younger elite athletes in the combined leg press and the right leg press exercises (P<0.05). [Table 6.11]

<table>
<thead>
<tr>
<th></th>
<th>Combined Leg Press</th>
<th>Right Leg Press</th>
<th>Left Leg Press</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Elite kg</td>
<td>Non-Elite kg</td>
<td>Elite kg</td>
</tr>
<tr>
<td></td>
<td>(n)</td>
<td>(n)</td>
<td>(n)</td>
</tr>
<tr>
<td>12 years</td>
<td>72±6</td>
<td>88±7</td>
<td>47±4</td>
</tr>
<tr>
<td></td>
<td>(6)</td>
<td>(11)</td>
<td>(6)</td>
</tr>
<tr>
<td>13 years</td>
<td>95±6</td>
<td>89±3</td>
<td>58±4</td>
</tr>
<tr>
<td></td>
<td>(13)</td>
<td>(23)</td>
<td>(13)</td>
</tr>
<tr>
<td>14 years</td>
<td>102±3</td>
<td>98±4</td>
<td>63±2</td>
</tr>
<tr>
<td></td>
<td>(20)</td>
<td>(21)</td>
<td>(20)</td>
</tr>
<tr>
<td>15 years</td>
<td>101±5</td>
<td>98±3</td>
<td>61±3</td>
</tr>
<tr>
<td></td>
<td>(19)</td>
<td>(31)</td>
<td>(19)</td>
</tr>
<tr>
<td>16 years</td>
<td>119±7</td>
<td>95±7</td>
<td>73±5</td>
</tr>
<tr>
<td></td>
<td>(13)</td>
<td>(13)</td>
<td>(13)</td>
</tr>
<tr>
<td></td>
<td>NS Group</td>
<td>NS Group</td>
<td>NS Group</td>
</tr>
<tr>
<td></td>
<td>Main Effect Age P&lt;0.01</td>
<td>Main Effect Age P&lt;0.01</td>
<td>Main Effect Age P&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>Age x Group P&lt;0.05</td>
<td>Age x Group P&lt;0.05</td>
<td>Age x Group P&lt;0.05</td>
</tr>
</tbody>
</table>
The analysis by maturation status of the leg strength measures performed on a Concept2 Dyno® by elite and non-elite athletes showed a main effect of group, for the combined leg press (P<0.01) and the left leg press (P<0.05) with the elite girls able to press more weight in both exercises than the non-elite girls. There was a main effect of maturation for all three leg press exercises (P<0.01), with the more mature girls able to press greater loads than the less mature girls. [Table 6.12]

Table 6.12 Combined leg, right leg, and left leg strength measures (kg) performed on a Concept2 Dyno® for elite and non-elite adolescent female sports performers by Tanner stage (PH) (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Tanner Stage (PH)</th>
<th>Combined Leg Press kg</th>
<th>Right Leg Press kg</th>
<th>Left Leg Press kg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Elite kg (n)</td>
<td>Non-Elite kg (n)</td>
<td>Elite kg (n)</td>
</tr>
<tr>
<td>Tanner Stage 2 (PH)</td>
<td>84±7 (11)</td>
<td>77±7 (8)</td>
<td>48±4 (11)</td>
</tr>
<tr>
<td>Tanner Stage 3 (PH)</td>
<td>99±5 (17)</td>
<td>92±3 (16)</td>
<td>63±4 (17)</td>
</tr>
<tr>
<td>Tanner Stage 4 (PH)</td>
<td>104±5 (24)</td>
<td>95±3 (42)</td>
<td>63±3 (24)</td>
</tr>
<tr>
<td>Tanner Stage 5 (PH)</td>
<td>108±5 (19)</td>
<td>100±4 (30)</td>
<td>67±3 (19)</td>
</tr>
</tbody>
</table>

Main Effect Group
P<0.01
Main Effect Maturation
P<0.01
Main Effect Group
NS
Main Effect Maturation
P<0.01
Main Effect Maturation
P<0.01
Main Effect Maturation
P<0.01
The analysis by age of arm strength measures performed on a Concept2 Dyno® by elite and non-elite athletes showed a main effect of group (P<0.05), for the arm press with the elite girls able to press more kilogrammes with both arms than the non-elite girls. There was a main effect of age for both the arm press and the arm pull exercises (P<0.01), with the older girls able to press greater loads than the younger girls. There was an interaction of age x group (P<0.05) for the arm pull exercise with the older elite girls able to pull more than the younger elite girls. [Table 6.13]

**Table 6.13** Arm press and arm pull strength measures (kg) performed on a Concept2 Dyno® for elite and non-elite adolescent female sports performers by age (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Group Number</th>
<th>Elite 12 years</th>
<th>Non-Elite 12 years</th>
<th>Elite 13 years</th>
<th>Non-Elite 13 years</th>
<th>Elite 14 years</th>
<th>Non-Elite 14 years</th>
<th>Elite 15 years</th>
<th>Non-Elite 15 years</th>
<th>Elite 16 years</th>
<th>Non-Elite 16 years</th>
<th>Main Effect Group P&lt;0.05</th>
<th>Main Effect Age P&lt;0.01</th>
<th>Age x Group P&lt;0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 years</td>
<td>27±2 (6)</td>
<td>30±3 (11)</td>
<td>36±2 (13)</td>
<td>33±2 (23)</td>
<td>39±1 (19)</td>
<td>37±1 (21)</td>
<td>40±2 (18)</td>
<td>36±1 (31)</td>
<td>45±2 (13)</td>
<td>38±2 (13)</td>
<td>NS Group</td>
<td>Main Effect Age P&lt;0.01</td>
<td></td>
</tr>
<tr>
<td>13 years</td>
<td>27±1 (6)</td>
<td>32±3 (11)</td>
<td>35±2 (13)</td>
<td>33±1 (23)</td>
<td>37±1 (19)</td>
<td>35±2 (21)</td>
<td>40±2 (18)</td>
<td>35±1 (31)</td>
<td>43±2 (13)</td>
<td>36±2 (13)</td>
<td>NS Group</td>
<td>Main Effect Age P&lt;0.01</td>
<td></td>
</tr>
<tr>
<td>14 years</td>
<td>27±1 (6)</td>
<td>32±3 (11)</td>
<td>35±2 (13)</td>
<td>33±1 (23)</td>
<td>37±1 (19)</td>
<td>35±2 (21)</td>
<td>40±2 (18)</td>
<td>35±1 (31)</td>
<td>43±2 (13)</td>
<td>36±2 (13)</td>
<td>NS Group</td>
<td>Main Effect Age P&lt;0.01</td>
<td></td>
</tr>
<tr>
<td>15 years</td>
<td>27±1 (6)</td>
<td>32±3 (11)</td>
<td>35±2 (13)</td>
<td>33±1 (23)</td>
<td>37±1 (19)</td>
<td>35±2 (21)</td>
<td>40±2 (18)</td>
<td>35±1 (31)</td>
<td>43±2 (13)</td>
<td>36±2 (13)</td>
<td>NS Group</td>
<td>Main Effect Age P&lt;0.01</td>
<td></td>
</tr>
<tr>
<td>16 years</td>
<td>27±1 (6)</td>
<td>32±3 (11)</td>
<td>35±2 (13)</td>
<td>33±1 (23)</td>
<td>37±1 (19)</td>
<td>35±2 (21)</td>
<td>40±2 (18)</td>
<td>35±1 (31)</td>
<td>43±2 (13)</td>
<td>36±2 (13)</td>
<td>NS Group</td>
<td>Main Effect Age P&lt;0.01</td>
<td></td>
</tr>
</tbody>
</table>

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Chapter 6

30 s Maximal Cycle Sprints and Strength

The analysis by maturation status of arm strength measures performed on a Concept2 Dyno® by elite and non-elite athletes showed a main effect of group, P<0.01, for the arm press with the elite girls able to press more kilogrammes with both arms than the non-elite girls. There was a main effect of maturation for both the arm press and the arm pull with the more mature girls able to move greater loads than the less mature girls (P<0.01). [Table 6.14]

Table 6.14  Arm press and arm pull strength measures (kg) performed on a Concept2 Dyno® for elite and non-elite adolescent female sports performers by Tanner stage (PH) (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th>Arm Press Strength</th>
<th>Elite</th>
<th>Non-Elite</th>
<th>Arm Pull Strength</th>
<th>Elite</th>
<th>Non-Elite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg</td>
<td></td>
<td>kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tanner Stage 2 (PH)</td>
<td>32±3</td>
<td>28±2</td>
<td>31±2</td>
<td>28±2</td>
<td></td>
</tr>
<tr>
<td>(n)</td>
<td>(11)</td>
<td>(8)</td>
<td>(11)</td>
<td>(8)</td>
<td></td>
</tr>
<tr>
<td>Tanner Stage 3 (PH)</td>
<td>39±2</td>
<td>33±1</td>
<td>37±1</td>
<td>33±1</td>
<td></td>
</tr>
<tr>
<td>(n)</td>
<td>(17)</td>
<td>(16)</td>
<td>(17)</td>
<td>(16)</td>
<td></td>
</tr>
<tr>
<td>Tanner Stage 4 (PH)</td>
<td>40±2</td>
<td>35±1</td>
<td>38±1</td>
<td>35±1</td>
<td></td>
</tr>
<tr>
<td>(n)</td>
<td>(24)</td>
<td>(42)</td>
<td>(24)</td>
<td>(42)</td>
<td></td>
</tr>
<tr>
<td>Tanner Stage 5 (PH)</td>
<td>41±2</td>
<td>38±1</td>
<td>41±2</td>
<td>35±1</td>
<td></td>
</tr>
<tr>
<td>(n)</td>
<td>(18)</td>
<td>(30)</td>
<td>(18)</td>
<td>(30)</td>
<td></td>
</tr>
<tr>
<td>Main Effect Group P&lt;0.01</td>
<td></td>
<td></td>
<td>NS Group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main Effect Maturation P&lt;0.01</td>
<td></td>
<td></td>
<td>Main Effect Maturation P&lt;0.01</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6.3.3 Elite Athlete subsets

When the results for the elite athletes were analysed by their subsets the 'individual endurance' athletes had lower peak power outputs (W) (P<0.01), and lower mean power outputs (W) (P<0.05), than the other elite subsets. When peak power outputs and mean power outputs were ratio scaled by body mass there were no significant differences between any of the elite subsets. However, when peak power outputs and mean power outputs were scaled by lean body mass (W.kg\(^{-1}\)) the 'individual endurance' athletes had lower peak power outputs by lean body mass (W.kg\(^{-1}\)) (P<0.01), and lower mean power outputs by lean body mass (W.kg\(^{-1}\)) (P<0.05) than the other elite subsets. [Table 6.15]
Chapter 6  30 s Maximal Cycle Sprints and Strength

Table 6.15  Peak power output (W) (W.kg⁻¹) and by lean body mass (W.kg⁻¹), Mean power output (W) (W.kg⁻¹) and by lean body mass (W.kg⁻¹) during a 30 second maximal bicycle sprint for elite adolescent female sports performers in the following groups: ‘team players’, ‘individual endurance’ athletes, ‘individual team players’ and ‘individual athletes from other disciplines’ by group (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th></th>
<th>Team Players</th>
<th>Individual Endurance</th>
<th>Individual Games</th>
<th>Individual Other</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Power Output</td>
<td>529 ± 26</td>
<td>399 ± 18</td>
<td>506 ± 22</td>
<td>496 ± 24</td>
<td>P&lt;0.01* Main Effect Group</td>
</tr>
<tr>
<td>(W)</td>
<td>(33)</td>
<td>(15)</td>
<td>(15)</td>
<td>(18)</td>
<td></td>
</tr>
<tr>
<td>Mean Power Output</td>
<td>371 ±15</td>
<td>304 ± 13</td>
<td>364 ± 18</td>
<td>343 ± 15</td>
<td>P&lt;0.05** Main Effect Group</td>
</tr>
<tr>
<td>(W)</td>
<td>(33)</td>
<td>(15)</td>
<td>(15)</td>
<td>(18)</td>
<td></td>
</tr>
<tr>
<td>Fatigue Index %</td>
<td>52.6 ±1.6</td>
<td>46.4 ±5.3</td>
<td>51.0 ±3.4</td>
<td>54.0 ±2.1</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>(32)</td>
<td>(14)</td>
<td>(15)</td>
<td>(18)</td>
<td></td>
</tr>
<tr>
<td>Peak Power Output</td>
<td>8.84 ±0.27</td>
<td>7.94 ±0.29</td>
<td>9.11 ±0.28</td>
<td>9.01 ±0.34</td>
<td>NS</td>
</tr>
<tr>
<td>(W.kg⁻¹)</td>
<td>(33)</td>
<td>(15)</td>
<td>(15)</td>
<td>(18)</td>
<td></td>
</tr>
<tr>
<td>Mean Power Output</td>
<td>6.21 ±0.13</td>
<td>6.07 ±0.23</td>
<td>6.56 ±0.29</td>
<td>6.22 ±0.17</td>
<td>NS</td>
</tr>
<tr>
<td>(W.kg⁻¹)</td>
<td>(33)</td>
<td>(15)</td>
<td>(15)</td>
<td>(18)</td>
<td></td>
</tr>
<tr>
<td>Peak Power Output</td>
<td>11.3 ±0.4</td>
<td>10.3 ±0.4</td>
<td>12.8 ±0.8</td>
<td>12.2 ±0.4</td>
<td>P&lt;0.01*** Main Effect Group</td>
</tr>
<tr>
<td>(W.kg⁻¹) by Lean Body Mass</td>
<td>(21)</td>
<td>(15)</td>
<td>(9)</td>
<td>(18)</td>
<td></td>
</tr>
<tr>
<td>Mean Power Output</td>
<td>8.22 ±0.24</td>
<td>7.86 ±0.28</td>
<td>9.38 ±0.49</td>
<td>8.43 ±0.22</td>
<td>P&lt;0.05**** Main Effect Group</td>
</tr>
<tr>
<td>(W.kg⁻¹) by Lean Body Mass</td>
<td>(21)</td>
<td>(15)</td>
<td>(9)</td>
<td>(18)</td>
<td></td>
</tr>
</tbody>
</table>

Post Hoc:

* Team v Individual Endurance P<0.01
Individual Endurance v Individual Game P=0.065 (Tukey)
Individual Endurance v Individual Other P= 0.088 (Tukey)

** Team v Individual Endurance P<0.05

*** Individual Endurance v Individual Games P<0.05
Individual Endurance v Individual Other P<0.05

**** Individual Endurance v Individual Games P<0.05
Team v Individual Games P=0.068 (Tukey P=0.054)
When the elite athletes subsets blood lactate (mmol.l⁻¹) responses to a 30 second maximal bicycle sprint were analysed there were no differences between any of the subsets for either the post warm-up or the 2 min post-sprint blood lactate (mmol.l⁻¹) responses. When the 5 min post-sprint blood lactate (mmol.l⁻¹) response was analysed there were differences between the subsets showing that the ‘individual endurance’ athletes had a lower blood lactate response (mmol.l⁻¹) than the other elite subsets (P<0.05). [Table 6.16]

Table 6.16  Blood lactate responses (mmol.l⁻¹) to a 30 second maximal bicycle sprint for elite adolescent female sports performers in the following groups: ‘team players’, ‘individual endurance’ athletes, ‘individual team players’ and ‘individual athletes from other disciplines’ by group (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th></th>
<th>Team Players</th>
<th>Individual Endurance</th>
<th>Individual Games</th>
<th>Individual Other</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resting lactate (mmol.l⁻¹)</td>
<td>1.08 ± 0.11</td>
<td>1.23 ± 0.11</td>
<td>0.90 ± 0.10</td>
<td>1.35 ± 0.05</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>(12)</td>
<td>(12)</td>
<td>(2)</td>
<td>(14)</td>
<td></td>
</tr>
<tr>
<td>3 min post warm-up lactate (mmol.l⁻¹)</td>
<td>2.67 ± 0.19</td>
<td>2.15 ± 0.17</td>
<td>2.14 ± 0.46</td>
<td>2.79 ± 0.17</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>(31)</td>
<td>(14)</td>
<td>(14)</td>
<td>(18)</td>
<td></td>
</tr>
<tr>
<td>2 min post sprint lactate (mmol.l⁻¹)</td>
<td>8.64 ± 0.40</td>
<td>7.22 ± 0.42</td>
<td>8.37 ± 0.35</td>
<td>8.09 ± 0.34</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>(33)</td>
<td>(14)</td>
<td>(14)</td>
<td>(19)</td>
<td></td>
</tr>
<tr>
<td>5 min post sprint lactate (mmol.l⁻¹)</td>
<td>8.99 ± 0.53</td>
<td>6.82 ± 0.41</td>
<td>7.83 ± 0.53</td>
<td>8.33 ± 0.49</td>
<td>P&lt;0.05* Main Effect Group</td>
</tr>
<tr>
<td></td>
<td>(32)</td>
<td>(15)</td>
<td>(14)</td>
<td>(16)</td>
<td></td>
</tr>
</tbody>
</table>

* Post Hoc:  Team v Individual Endurance P<0.05
There were no strength differences between any of the elite athlete subsets, though the individual endurance athletes consistently had lower values for all of the strength tests than any of the other subsets of elite athletes. [Table 6.17]

Table 6.17  Strength measures (kg) performed on a Concept2 Dyno® for elite adolescent female sports performers in the following groups: ‘team players’, ‘individual endurance’ athletes, ‘individual team players’ and ‘individual athletes from other disciplines’ by group (mean ± SE). Group numbers are indicated by the figure in the brackets.

<table>
<thead>
<tr>
<th></th>
<th>Team Players</th>
<th>Individual Endurance</th>
<th>Individual Games</th>
<th>Individual Other</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined Leg Press (kg)</td>
<td>106±5</td>
<td>98±5</td>
<td>105±7</td>
<td>99±5</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>(27)</td>
<td>(15)</td>
<td>(10)</td>
<td>(20)</td>
<td></td>
</tr>
<tr>
<td>Right Leg Press (kg)</td>
<td>62±3</td>
<td>58±3</td>
<td>69±4</td>
<td>60±3</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>(27)</td>
<td>(15)</td>
<td>(10)</td>
<td>(20)</td>
<td></td>
</tr>
<tr>
<td>Left Leg Press (kg)</td>
<td>61±3</td>
<td>60±3</td>
<td>69±5</td>
<td>60±3</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>(27)</td>
<td>(15)</td>
<td>(10)</td>
<td>(20)</td>
<td></td>
</tr>
<tr>
<td>Arm Press (kg)</td>
<td>39±2</td>
<td>36±2</td>
<td>38±3</td>
<td>40±2</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>(27)</td>
<td>(14)</td>
<td>(10)</td>
<td>(19)</td>
<td></td>
</tr>
<tr>
<td>Arm Pull (kg)</td>
<td>38±2</td>
<td>36±2</td>
<td>38±2</td>
<td>38±2</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>(27)</td>
<td>(14)</td>
<td>(10)</td>
<td>(19)</td>
<td></td>
</tr>
</tbody>
</table>
6.4 Discussion

The main findings in this study were that when peak power outputs (W) were analysed by both maturation and age there were no effects of group but that there were effects of maturation (P<0.01) and age (P<0.01), indicating that as the cohort grew older in age and became more mature, as defined by the Tanner scale for pubic hair, they became stronger and were able to produce a greater peak power during a 30 second maximal cycle sprint (W) but not when ratio scaled by body mass (W.kg\(^{-1}\)). Peak power is an indication of the ability of leg muscles to produce short term mechanical power (Van Praagh and Doré, 2002), short term being classed as the maximum amount of power that can be produced in one or two seconds.

Doré et al (2001) in one of the very few studies of females and cycle sprints, looked at peak and mean power outputs from cycle sprints in prepubescent (n=64), adolescent (n=62) and young adult (n=63) females. Maturation status was not recorded. Doré et al., used body mass, fat free mass (calculated from body mass and body fat percentage) and lean leg volume (calculated from anthropometric measurements) as variables in their research and then used linear regression standards in their statistical analyses, and found that differences in performance during anaerobic cycling were primarily dependent upon the body dimensions of the participants which tended to increase with age group, with adult females exhibiting greater peak power than both of the other groups, even when expressed relative to fat free mass or lean leg volume (Doré et al., 2001).

When the mean power outputs (W) and (W.kg\(^{-1}\)) from the 30 second maximal cycle sprints were analysed there was a main effect of group whether analysed by maturation status (P<0.01) or by age (P<0.01) with the elite girls producing a higher mean power output (W and W.kg\(^{-1}\)) during the 30 second maximal cycle sprint than the non-elite girls. There was also an effect of maturation (P<0.01) and of age (P<0.01) for mean power outputs (W) showing that the older and more mature girls were able to produce a higher mean power output (W) than the younger and less mature girls. Mean power output during 30 second maximal cycle sprinting is a reflection of the muscular endurance capability of the large muscles of the thigh. That the elite athletes in the
current study had higher mean power outputs than the non-elite athletes suggests that the well trained elite athletes had greater endurance capacity than the non-elite athletes. The fatigue index showed that the elite athletes fatigued less quickly (P<0.01) than the non-elite athletes during the 30 second maximal cycle sprint, this is in line with the higher mean power outputs (W and W.kg-1) reported above and the fact that mean power output is an expression of the local muscle endurance of the legs (Van Praagh and Doré, 2002), confirming that the elite athletes had greater local muscle endurance than the non-elite athletes.

Blood lactate concentrations (mmol.l-1) when analysed by maturation status and age only showed differences between the elite and non-elite athletes during the post warm-up stage where the elite athletes had lower (P<0.01) lactate concentrations (mmol.l-1) than the non-elite athletes for both variables. Blood lactate concentrations (mmol.l-1) during the 2 minute post-sprint and 5 min post-sprint stages showed no differences between the groups though there were main effects of both maturation (P<0.01), and age (P<0.01), with the more mature and older girls having higher lactate concentrations (mmol.l-1) than the less mature and younger girls. It is known that both children and adolescents respond to all levels and intensities of exercise with lower blood lactate values than adults (Welsman and Armstrong, 1998). Because of the ethical constraints placed on researchers when working with children and adolescents it has not usually been possible for invasive intramuscular investigation into this phenomenon to take place, although there is some evidence from the rare early studies that did perform muscle biopsies in children (all boys), to suggest that muscle stores of glycogen in children are lower than those in adults, and that they increase with age (Karlsson et al., 1972; Eriksson and Saltin, 1974; Welsman and Armstrong, 1998). Blood lactate levels are a reflection of the processes by which lactate is produced and removed, therefore post-exercise blood lactate concentration only provides an indication of the amount of stress placed on the anaerobic metabolism by the particular exercise bout, rather than a quantitative measure of glycolysis (Van Praagh and Doré, 2002). There was no effect of maturation found in a study comparing blood lactate concentration (mmol.l-1) following a 30 s supramaximal cycle test in boys (n=90) and girls (n=79) aged (mean ± SD) 12.2 ± 0.4 years who were recorded as being in one of the first four stages of maturation according to Tanner’s indices for pubic hair (Armstrong et al., 1997).
However, 61% (n=103) of this total cohort were in stages 1 and 2 with 62 % (n=64) of those being boys, who are known to have a later sexual maturation than girls. Furthermore, this cohort was a very homogenous group with a tight age range, suggesting careful pre-selection of subjects. This researcher, respectfully argues that it is not a common occurrence to have 12 year old boys at advanced stages of sexual maturation as defined by Tanner’s indices for pubic hair, whilst acknowledging that it is far more common for girls to be sexually mature at 12 years old while not prepubescent, and were all arguably at an age where further physical growth and maturation would be expected, thus increasing muscle mass, lean leg volume, and length, all of which will have an effect on the ability of the muscles to produce power and on the concentration of blood lactate (mmol.L⁻¹). It is sometimes difficult to distinguish between the degree of physical maturation and the degree of sexual maturation that a child has arrived at at any given point. This researcher contends that the significant effect of maturation found in the current study, as defined by Tanner’s indices for pubic hair, is also linked to the fact that the girls in the current study were older, taller and heavier and likely to be more advanced in their physical/somatic maturation than the girls and boys in the Armstrong et al., (1997) study discussed above.

This study also looked at the muscle strength of the girls tested. We used a Concept2 Dyno® which had the major advantage that all the participants in our study could use it safely with very little habituation and did not need to have prior experience of weight training, something that would have rendered this part of the study impossible otherwise, as due to the age of the majority of the participants very few of them had done any training with weights of any description. There is a paucity of studies looking at the strength of adolescent girls, particularly with such a large cohort as this study. In boys, muscular strength increases linearly with age from early childhood until 13 or 14 years of age when there is a marked increase in strength through puberty, followed by a slower increase until the mid 20’s (Armstrong and Welsman, 1997; Beunen and Malina, 1988). Girls also experience an increase in muscular strength until they are about 15 years old, but show no evidence of an adolescent spurt (Armstrong and Welsman, 1997). Strength is defined as the maximal force or torque that is generated by a muscle or muscle group during a single maximal voluntary effort (Blimkie and Bar-Or, 2008).
Chapter 6 30 s Maximal Cycle Sprints and Strength

The maximal force that can be generated by a skeletal muscle is a primarily due to the size of the muscle and neural control over force generation (Malina et al., 2004b). During childhood and adolescence growth of muscle tissue is characterised by constancy in the number of fibres, an increase in fibre size and number of nuclei, and an increase in overall muscle mass. In the current study, when analysed by maturation stage, the elite girls were stronger $P<0.01$, than the non-elite girls in all measures, except for the right leg press exercise and the arm pull exercise where there was no effect of group. However there was a main effect of maturation in all the strength measures $P<0.01$ when measured by maturation stage with the more mature girls being stronger than the less mature girls. When the strength measures were analysed by age there was no effect of group except for the arm press exercise where the elite girls were stronger ($P<0.01$) than the non-elite girls. There was a main effect of age ($P<0.01$) for all the strength measures with the older girls being stronger than the younger girls.

6.5 Conclusion

In conclusion, this study supports the hypothesis that the elite female adolescent athletes will have higher peak power output responses for absolute (W), and by lean body mass (W.kg$^{-1}$) when compared by age, and higher mean power output responses for absolute (W), and by ratio-scaled (W.kg$^{-1}$) to a 30 s cycle ergometer sprint test when compared by age and maturity. The results for blood lactate response were less clear with there being effects for age and maturity but not for group except at the post warm-up stage. The blood lactate responses at all measurement points increase with age and with maturity, suggesting that, in girls, both age and maturity have a positive effect on blood lactate concentration after maximal exercise.

This study finds that the elite female adolescent athletes are stronger than the non-elite female adolescent athletes when tested on a Concept2 Dyno® when analysed by maturation stage in all tests except the right leg press strength and the arm pull strength measures. There was a main effect of maturation and a main effect of age for all of the strength measures, suggesting that, in girls, whether or not a girl is strength trained, both age and maturity have a positive effect on muscular strength as assessed by Concept2 Dyno®.
Chapter 7

Psychological Determinants of Success in Elite Female Adolescent Athletes

7.1 Introduction

The motivation that drives an athlete to succeed has been extensively studied over the past two decades. Nicholls' achievement goal theory (Nicholls, 1984) which was developed in education, was extensively researched and applied to sports situations by Duda (1989) and Roberts (1984) and colleagues. As the creation and development of elite athletes becomes ever more important to the governing bodies of sport and to central government, it is thought to be important that those elite athletes possess the necessary psychological traits and skill sets to assist them in achieving their goals. The motivational and achievement environment surrounding elite athletes has been cited by many of them to have played a major part in their success (Gould et al., 2002). When dealing with young elite athletes at the outset of their careers there are many factors that can influence their development and progression into elite sports as an adult.

Nicholls' (1984) achievement goal theory forms the basis for much of the sport and exercise psychology all over the world (Harwood et al., 2004). Achievement goal theory refers to the different ways that individuals construe their personal levels of competence for particular tasks. The different states of achievement have been identified as 'task' involvement and 'ego' involvement (Nicholls, 1984). Psychological motivational orientations fall into two main categories; task orientation and ego orientation. A task involved goal is activated when an individual focuses on the development of competence. Their sense of achievement will be self-referenced and subjectively associated with personal mastery, progress and self-improvement. An ego involved goal comes about when an individual focuses on the demonstration of superior competence to others, where their sense of achievement and personal adequacy is normatively referenced and associated with showing a superior capacity or ability, i.e. they are doing it to show others how good they are, how much better than others they are – they want to please others.
Individuals may have a disposition towards one type or the other of goal involvement, i.e. having trait-like tendencies to be either task or ego goal oriented; these may be as a result of socialisation through the prevailing motivational climate in the home or the classroom (Roberts et al., 1998), though Harwood et al. (2000) do not agree that this is necessarily the case and that “definitions of task and ego involvement in the classroom might not generalise to sport” (Harwood et al., 2000). Individuals are capable of being high, moderate or low in both orientations in combination (Harwood et al., 2004). Goal orientations are orthogonal, which means that levels of each goal orientation can vary within each individual; thus an individual could have a combined low level of task orientation and low level of ego orientation, or any of the other three combinations possible, i.e. high task/high ego; high task/low ego; low task/high ego (Harwood et al., 2008).

Task orientation is associated with positive psychological responses, having positive correlations with enjoyment, intrinsic motivation and adaptive moral values and behaviours (Harwood et al., 2004). Duda (2001) stated that it is important that sports psychologists “do whatever is possible to make sure that an athlete’s task orientation is robust” (Duda, 2001 p 163). Ego orientation does not automatically lead to negative psychological qualities (such as deceptive strategies and cheating (Duda and Nicholls, 1992)), particularly when it is in combination with a task orientation of the same level (Harwood et al., 2004) however, Duda (2001) stated that “ego involvement might best be tempered (perhaps via manipulation of the motivational climate) and certainly not promoted” (Duda, 2001). An athlete with a high task/high ego orientation is likely to be more motivated to work hard and develop personal mastery in order to demonstrate superior abilities to others (Harwood et al., 2004).

The motivational climate of an individual will be affected by a variety of factors in their environment. The way that an individual engages in and responds to achievement activities, as well as the reasons surrounding the ‘why’ of their participation in particular achievement activities, is all part of the study of achievement motivation that has been heavily researched in the last 30 – 40 years (Ames, 1992). The research has primarily investigated and focused on defining adaptive patterns of motivation and separating them from maladaptive patterns (Ames, 1992). The bulk of this early
research took place in schools and educational establishments but the findings can, and have been, translated to the sporting environment as well as to other settings (Dweck, 1986; Ames, 1992). Ames refers to a mastery goal orientation, though this has variously been labelled as learning goal (Dweck, 1986) and task involvement (Nicholls, 1984). The goal preference (or motivation) of each individual becomes apparent when they are faced with having to make a choice or a decision (Dweck, 1986; Ames, 1992). In a sporting context coaches make clear their goals by the design of the training sessions, by how they encourage their athletes', by the characteristics that they perceive as desirable, by how they recognise success and effort from the sports performer, by how they instil discipline. Similarly a parent will give a clear indication to a child or young athlete of what their personal goal or motivation is when they ask ‘did you win?’ or ‘how did training go tonight? Did you enjoy it?’ (Ames, 1992).

Organised sport involves participants in achievement situations where outcomes are important and valued, and evaluation of performance is both formal and externally imposed, with individual performance being public and exposed. This leads to a situation where individual self-worth can be linked to normative comparisons (Ames, 1992). It is in these types of settings that an individual’s achievement behaviour can be related to their improvement and progress towards individual goals, or can be viewed in relation to normative standards. The decision an individual has to make is whether to focus on learning new skills and developing their existing abilities, or to focus on demonstrating and protecting their ability (Ames, 1992). Achievement may be defined as “the attainment of a personally or socially valued goal” (Roberts, 2001). Individuals will have different goals, but the attainment of that goal will be seen to be either personally or socially valuable. Thus achievement is defined subjectively, with success or failure in attainment of the goal being a subjective state based on the outcome of the achievement as evaluated by the individual participant (Spink and Roberts, 1980; Roberts, 2001). Ames (1992) posited that “the coach ..can enable participants to adopt a mastery orientation if they (the coach) establish a structure that conveys a mastery orientation” (Ames, 1992).

There is a paucity of research in the literature that compares the psychological profile and psychological skills usage of elite female adolescent athletes in comparison to non-
Thus, this study will test the hypothesis that the elite female adolescent sports performer will be more highly intrinsically motivated, have a higher task orientation, believe that their success comes primarily through effort and make wider use of psychological skills in practice and in competition than the non-elite female adolescent sports performer.
Chapter 7

7.2 Methods
Sixty six elite female adolescent athletes and sixty one non-elite female adolescent athletes agreed to participate. All participants were asked to complete a series of psychological questionnaires (see below), although it was made clear to the non-elite participants that some or many of the questions might not be relevant to them. The aim of the questionnaires was to establish a ‘psychological profile’ of young performers whilst training and competing in their sport. The participants were given all the psychological questionnaires at the start of the testing day and were asked to complete them in the gaps when they were not being physically tested on the treadmill or cycle ergometer. The participants were instructed to ask a researcher if there was a question that they needed to be clarified and were asked not to consult with each other. Each participant had a clipboard for all their paperwork and questionnaires for the day. Once the questionnaires were completed they were attached to the clipboard. Dyslexic participants were able to have a researcher to read the questions to them and record their scores where necessary.

7.3.1 TOPS - Test of Performance Strategies. (Thomas et al., 1999) (Appendix H).
This is a 64 item questionnaire designed to look at the psychological strategies and skills used by sports performers. TOPS examines ‘activation’, ‘relaxation’, ‘imagery’, ‘goal-setting’, ‘self-talk’, ‘automaticity’ ‘emotional control’ and ‘negative thinking / attentional control skills’ both in training and competition. The young performers rated the frequency of their use of a particular skill on a scale of 1 (never use) to 5 (always use).

7.3.2 ICMCS - Individual Sport Motivated Climate Scales (Appendix I).
This is a partially validated profiling tool, in development at Loughborough University (Smith and Harwood, 2004). The scale looks at the motivational climate of the performer and has been specifically designed to look at the motivational climate for those participating in individual sports rather than team sports. The ICMCS looks at the young performer’s relationships with their coach; their father; their mother; their peers; and the reward structure of their sport.
7.3.3 SIMS - Situational Motivational Scale (Guay et al., 2000) (Appendix K)
This is a 16 item measurement of the constructs of intrinsic motivation, identified regulation, external regulation and amotivation that might be demonstrated by a performer. The participants were asked to respond to a series of questions about the reasons why they were currently engaged in their sport [scale of 1 (not at all) to 7 (exactly)]. Analysis of responses enables the motivations for a performer’s participation in sport to be established.

7.3.4 BASQ – Beliefs About the causes of Success Questionnaire (White et al., 1988; White et al., 2004) (Appendix J)
This is a 12 item measurement of the performer’s beliefs about the causes of success. The analysis of the results enables the researcher to assess what part the young performer feels that the constructs of effort and ability play in their success in sport. The young performers were asked to respond to a series of statements on a scale of 1 (strongly disagree) to 5 (strongly agree).

This is a 12 item measurement of task and ego orientation. Participants were asked to respond to a series of statements on a scale from A (strongly agree) to E (strongly disagree). The analysis of the responses given enables the task and ego orientation of the performer to be assessed.

7.3.6 Statistics
Statistics were computed using a ONE-WAY ANOVA (SPSS). Effect size was calculated using the equation given by Field (2005a pp 357). Effect sizes are traditionally categorised as either ‘small’, ‘medium’, or ‘large’. Cohen, (1988, 1992 op. cit Field, 2005) made widely accepted suggestion that the following values indicate the size of the effect.

\[ r = .10 \text{ (small effect): the effect explains 1% of the total variance.} \]
\[ r = .30 \text{ (medium effect): the effect accounts for 9% of the total variance} \]
\[ r = .50 \text{ (large effect): the effect accounts for 25% of the total variance.} \]
An effect size is an objective and standardised measure of the magnitude of the observed effect (Field, 2005b pp 32) which allows comparison across different studies that may have measured different variables or used different scales of measurement.

7.4 Results

7.4.1. Test of Performance Strategies (TOPS)

7.4.1.i Practice
Table 7.1 shows the results of the Test of Performance Strategies in practice for the elite and non elite girls who participated in the current study. There were no significant differences between the two groups of girls except for the use of imagery and attentional control constructs, both of which the elite girls were significantly (P<0.01) more likely to use or develop than the non-elite girls. The imagery construct statements were 'during practice I visualise successful past performances'; 'I rehearse my performance in my mind before practice'; 'at practice, when I visualise my performance, I imagine what it will feel like', and 'at practice, when I visualise my performance, I imagine watching myself as if on a video replay'. The attentional control construct statements were 'my attention wanders while I am training'; 'I am able to control distracting thoughts when I am training'; 'during practice I focus my attention effectively', and 'I have trouble maintaining my concentration during long practices'.

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### Table 7.1 Results of the Test of Performance Strategies in Practice for Elite and Non-elite adolescent female sports performers (mean ± SEM)

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean ± SEM</th>
<th>N</th>
<th>Sig</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOPS PRACTICE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Activation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite Athletes</td>
<td>2.98 ± 0.06</td>
<td>66</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>Non-Elite Athletes</td>
<td>2.93 ± 0.08</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2.96 ± 0.05</td>
<td>126</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Relaxation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite Athletes</td>
<td>2.25 ± 0.08</td>
<td>66</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>Non-Elite Athletes</td>
<td>2.29 ± 0.11</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2.27 ± 0.07</td>
<td>126</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Imagery</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite Athletes</td>
<td>3.18 ± 0.10</td>
<td>66</td>
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<tr>
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<tr>
<td>Total</td>
<td>2.97 ± 0.07</td>
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<tr>
<td><strong>Goal-Setting</strong></td>
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</tr>
<tr>
<td>Elite Athletes</td>
<td>3.35 ± 0.08</td>
<td>66</td>
<td>NS</td>
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</tr>
<tr>
<td>Non-Elite Athletes</td>
<td>3.18 ± 0.10</td>
<td>60</td>
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<tr>
<td>Total</td>
<td>3.27 ± 0.06</td>
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<tr>
<td><strong>Self-Talk</strong></td>
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</tr>
<tr>
<td>Elite Athletes</td>
<td>3.30 ± 0.08</td>
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<tr>
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<td>3.17 ± 0.07</td>
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<td>NS</td>
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<tr>
<td>Non-Elite Athletes</td>
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<td>Total</td>
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<td><strong>Emotional Control</strong></td>
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</tr>
<tr>
<td>Elite Athletes</td>
<td>3.25 ± 0.09</td>
<td>66</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>Non-Elite Athletes</td>
<td>3.08 ± 0.10</td>
<td>60</td>
<td></td>
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</tr>
<tr>
<td>Total</td>
<td>3.17 ± 0.06</td>
<td>126</td>
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<td></td>
</tr>
<tr>
<td><strong>Attentional Control</strong></td>
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<td></td>
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<tr>
<td>Elite Athletes</td>
<td>3.51 ± 0.08</td>
<td>66</td>
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<td>.48</td>
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<tr>
<td>Non-Elite Athletes</td>
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<td>60</td>
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</tr>
<tr>
<td>Total</td>
<td>3.35 ± 0.06</td>
<td>126</td>
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</table>
7.4.1.11 Competition

Table 7.2 shows the results of the Test of Performance Strategies in competition for the elite and non-elite girls in the current study. There were no significant differences between the groups except for the use of activation and goal-setting constructs, both of which the elite girls were significantly (P<0.01) more likely to use than the non-elite girls. The activation construct statements were 'I can raise my energy levels at competitions when necessary'; 'I psych myself up at competitions to get ready to perform'; 'I do what needs to be done to get psyched up for competitions', and 'I can increase my energy to just the right level for competitions'. The statements used for the goal-setting construct were 'during competition I set specific result goals for myself'; 'I evaluate whether I achieve my competition goals'; 'I set very specific goals for competition', and 'I set personal performance goals for competition'.
### Table 7.2 Results of the Test of Performance Strategies in Competition for Elite and Non-Elite adolescent female sports performers (mean ± SEM)

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean</th>
<th>SEM</th>
<th>N</th>
<th>Sig</th>
<th>Effect Size</th>
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<td>0.08</td>
<td>66</td>
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<tr>
<td>Non-Elite Athletes</td>
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<tr>
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<tr>
<td>Non-Elite Athletes</td>
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<tr>
<td>Total</td>
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<td>0.07</td>
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<tr>
<td><strong>TOPS COMPETITION Imagery</strong></td>
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<tr>
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<td>Non-Elite Athletes</td>
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<tr>
<td>Total</td>
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<td><strong>TOPS COMPETITION Goal-Setting</strong></td>
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<td>P&lt;0.01</td>
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<td>3.61</td>
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<tr>
<td>Non-Elite Athletes</td>
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<tr>
<td>Elite Athletes</td>
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<td>0.10</td>
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<tr>
<td>Non-Elite Athletes</td>
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<td>0.12</td>
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<td></td>
</tr>
<tr>
<td><strong>TOPS COMPETITION Automaticity</strong></td>
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<td></td>
<td>NS</td>
<td></td>
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<td>66</td>
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<tr>
<td>Non-Elite Athletes</td>
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<td><strong>TOPS COMPETITION Emotional Control</strong></td>
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<td><strong>TOPS COMPETITION Negative Thinking</strong></td>
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<td>0.09</td>
<td>66</td>
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<tr>
<td>Non-Elite Athletes</td>
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<tr>
<td>Total</td>
<td>2.46</td>
<td>0.07</td>
<td>126</td>
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</table>
7.4.2 Individual Sport Motivated Climate Scales

Table 7.3 shows the results of the coach section of the individual sport motivated climate scales. The elite athletes thought (P<0.01) that coaches were more likely to have ego involving behaviours and that the coaches were (P>0.05) more likely to use task involving behaviours and have task involving values/attitudes than the non-elite athletes. A typical statement for task involving behaviours would be ‘before competition my coach directs my attention to how I am going to produce my best skills’. A typical statement for ego involving behaviours would be ‘my coach looks back at my achievements in terms of how much I showed greater skills or strengths than my opposition’. A typical statement for task involving values/attitudes would be ‘my coach sees my mistakes as part of my performance improvement’. A typical statement

<table>
<thead>
<tr>
<th>Table 7.3</th>
<th>Results of the Individual Sport Motivated Climate Scales (ICMCS) - Coach - for Elite and Non-Elite adolescent female sports performers (mean ± SEM)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean</th>
<th>SEM</th>
<th>N</th>
<th>Sig</th>
<th>Effect Size</th>
</tr>
</thead>
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<tr>
<td><strong>ICMCS - COACH</strong></td>
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<td></td>
<td></td>
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<td><strong>Task Involving Behaviours</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Elite Athletes</td>
<td>5.58</td>
<td>0.10</td>
<td>66</td>
<td>P&lt;0.05</td>
<td>.47</td>
</tr>
<tr>
<td>Non-Elite Athletes</td>
<td>5.18</td>
<td>0.15</td>
<td>54</td>
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<tr>
<td>Total</td>
<td>5.40</td>
<td>0.09</td>
<td>120</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ICMCS - COACH</strong></td>
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</tr>
<tr>
<td><strong>Ego Involving Behaviours</strong></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Elite Athletes</td>
<td>5.21</td>
<td>0.12</td>
<td>66</td>
<td>P&lt;0.01</td>
<td>.51</td>
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<tr>
<td>Non-Elite Athletes</td>
<td>4.70</td>
<td>0.15</td>
<td>54</td>
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</tr>
<tr>
<td>Total</td>
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<td>0.10</td>
<td>120</td>
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<td></td>
</tr>
<tr>
<td><strong>ICMCS - COACH</strong></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>Task Involving Values/Attitudes</strong></td>
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<td>66</td>
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<td>Total</td>
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<td>0.08</td>
<td>120</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ICMCS - COACH</strong></td>
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<td></td>
<td></td>
</tr>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite Athletes</td>
<td>2.07</td>
<td>0.17</td>
<td>66</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>Non-Elite Athletes</td>
<td>2.25</td>
<td>0.22</td>
<td>54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2.15</td>
<td>0.14</td>
<td>120</td>
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</table>
Table 7.4 shows the results of the father section of the individual sport motivated climate scales. The elite athletes thought that their fathers displayed more ego involving values and task involving values (P<0.01) than the non-elite girls. The elite athletes thought that they were more likely to use a positive affective style of reinforcement (P<0.05) than the non-elite athletes. There was a trend (P=0.060) for the elite girls to be significantly more likely to have a father with a negative affective style of reinforcement than the non-elite girls. In the construct Father - Ego Involving Values a typical statement would be, ‘my father is proud of me if I show greater skills or strengths than my opposition’. In the construct Father - Task Involving Values a typical statement would be ‘before competition my father reminds me of the importance of doing my best’; in the construct Father - Positive Affective Style of Reinforcement a typical statement would be ‘my father views mistakes as part of learning’, in the construct Father- Negative Affective Style of Reinforcement a typical statement would be ‘my father is disappointed in me if I do not put in 100% effort’.

<table>
<thead>
<tr>
<th>Table 7.4</th>
<th>Results of the Individual Sport Motivated Climate Scales (ICMCS) - Father - for Elite and Non-Elite adolescent female sports performers (mean ± SEM)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group</strong></td>
<td><strong>Mean</strong></td>
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<tr>
<td>ICMCS - FATHER Ego Involving Values</td>
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<tr>
<td>Elite Athletes</td>
<td>4.13</td>
</tr>
<tr>
<td>Non-Elite Athletes</td>
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</tr>
<tr>
<td>Total</td>
<td>3.66</td>
</tr>
<tr>
<td>ICMCS - FATHER Task Involving Values</td>
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</tr>
<tr>
<td>Elite Athletes</td>
<td>5.22</td>
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<td>Non-Elite Athletes</td>
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<td>ICMCS - FATHER Positive Affective Style of Reinforcement</td>
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<td>Elite Athletes</td>
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<td>Non-Elite Athletes</td>
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<tr>
<td>Total</td>
<td>5.82</td>
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</table>
Table 7.5 shows the results of the Mother section of the individual sport motivated climate scales. The elite girls were significantly (P<0.01) more likely than the non-elite girls to think that their mothers’ displayed ego involving values. There was a trend (P=0.056) for the elite girls to think that their mothers’ displayed higher task involving values than the non-elite girls. A typical statement in the construct Mother - ego involving values would be ‘to my mother, success is about being better than your opponent or other competitors’. A typical statement in the construct Mother – task involving values would be ‘my mother encourages me to review how I performed to help me learn from competition’. A typical statement in the construct Mother – negative affective style of reinforcement would be ‘my mother is annoyed if I make a mistake when performing’.

Table 7.5 Results of the Individual Sport Motivated Climate Scales (ICMCS) - Mother - for Elite and Non-Elite adolescent female sports performers (mean ± SEM)

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean</th>
<th>SEM</th>
<th>N</th>
<th>Sig</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICMCS – MOTHER Ego Involving Values</td>
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<tr>
<td>Elite Athletes</td>
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<td>64</td>
<td>P&lt;0.01</td>
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<tr>
<td>Non-Elite Athletes</td>
<td>2.89</td>
<td>0.15</td>
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<tr>
<td>Total</td>
<td>3.35</td>
<td>0.13</td>
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<td>ICMCS – MOTHER Task Involving Values</td>
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<td>P=0.056</td>
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<tr>
<td>Elite Athletes</td>
<td>5.47</td>
<td>0.11</td>
<td>65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Elite Athletes</td>
<td>5.09</td>
<td>0.17</td>
<td>57</td>
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<tr>
<td>Total</td>
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<td>0.10</td>
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<td>NS</td>
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<td>0.17</td>
<td>64</td>
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<tr>
<td>Non-Elite Athletes</td>
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<td>0.16</td>
<td>57</td>
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</tr>
<tr>
<td>Total</td>
<td>2.27</td>
<td>0.11</td>
<td>121</td>
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</table>
Table 7.6 shows the results of the Peer section of the individual sport motivated climate scales. There was a trend \((P=0.051)\) for the elite girls to think that their peers would be more likely to have task involving values than the non-elite girls. A typical statement in the construct Peer – task involving values and behaviours would be, 'other competitors don’t talk to me if I’ve lost’. A typical statement in the construct Peer – ego involving values would be, ‘other competitors would congratulate me on a great performance and effort even if I had lost’. A typical statement in the construct Peer – avoidance and neglect would be ‘being noticed by my opposition depends greatly on whether I beat them or not’.

**Table 7.6** Results of the Individual Sport Motivated Climate Scales (ICMCS) - Peers for Elite and Non-Elite adolescent female sports performers (mean ± SEM)

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean</th>
<th>SEM</th>
<th>N</th>
<th>Sig</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
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<td><strong>ICMCS – PEERS</strong></td>
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<td>Ego Involving Values</td>
<td>Elite Athletes</td>
<td>4.98</td>
<td>0.12</td>
<td>66</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Non-Elite Athletes</td>
<td>4.83</td>
<td>0.14</td>
<td>61</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>4.91</td>
<td>0.09</td>
<td>127</td>
<td></td>
</tr>
<tr>
<td><strong>Task Involving Values &amp; Behaviours</strong></td>
<td>Elite Athletes</td>
<td>5.21</td>
<td>0.10</td>
<td>66</td>
<td>P=0.051 .41</td>
</tr>
<tr>
<td></td>
<td>Non-Elite Athletes</td>
<td>4.89</td>
<td>0.13</td>
<td>61</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>5.06</td>
<td>0.08</td>
<td>127</td>
<td></td>
</tr>
<tr>
<td><strong>Avoidance and Neglect</strong></td>
<td>Elite Athletes</td>
<td>1.70</td>
<td>0.10</td>
<td>66</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Non-Elite Athletes</td>
<td>2.00</td>
<td>0.16</td>
<td>61</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1.85</td>
<td>0.09</td>
<td>127</td>
<td></td>
</tr>
</tbody>
</table>
Table 7.7 shows the results of the sport reward section of the individual sport motivated climate scales. There were no differences between the elite athletes and the non-elite athletes for this section. A typical statement in the construct Sport Reward – rewarding players of superior ability to others would be, ‘most of the opportunities that people gain in my sport depend upon if they win or what position they come’. A typical statement in the construct Sport Reward – credit to athletes for improving would be, ‘in my sport, you get rewarded in competition for the personal progress that you make’.

### Results of the Individual Sport Motivated Climate Scales (ICMCS) - Sport Reward - for Elite and Non-Elite adolescent female sports performers (mean ± SEM)

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean</th>
<th>SEM</th>
<th>N</th>
<th>Sig</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ICMCS – SPORT REWARD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rewarding Players of Superior Ability to Others</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite Athletes</td>
<td>4.59</td>
<td>0.15</td>
<td>66</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Elite Athletes</td>
<td>4.42</td>
<td>0.16</td>
<td>61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>4.51</td>
<td>0.11</td>
<td>127</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td><strong>ICMCS – SPORT REWARD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Credit to Athletes for Improving</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite Athletes</td>
<td>4.97</td>
<td>0.13</td>
<td>66</td>
<td></td>
<td>NS</td>
</tr>
<tr>
<td>Non-Elite Athletes</td>
<td>4.74</td>
<td>0.16</td>
<td>61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>4.86</td>
<td>0.10</td>
<td>127</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 7.8 shows the results of the influence of significant others and sporting reward structure for the individual sport motivated climate scales. The elite athletes were significantly (P<0.01) more likely to record influence from significant others than were the non-elite athletes. A typical question in this construct would be ‘How much does your coach (or father/mother/other players) affect your thoughts, feelings and behaviour in competition. The responses range from 1 = not at all to 7 = very much.

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean</th>
<th>SEM</th>
<th>N</th>
<th>Sig</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICMCS - B Influence from Significant Others and Sporting Reward Structure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite Athletes</td>
<td>5.00</td>
<td>0.11</td>
<td>66</td>
<td>P&lt;0.01</td>
<td>.51</td>
</tr>
<tr>
<td>Non-Elite Athletes</td>
<td>4.43</td>
<td>0.16</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>4.73</td>
<td>0.10</td>
<td>126</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
7.4.3 Beliefs about the causes of success (BASQ)

Table 7.9 shows the results of the Beliefs about the Causes of Success Questionnaire. There were no significant differences between the elite and non-elite athletes for either section. A typical statement from the effort section would be 'players succeed if they work really hard'. A typical question from the ability section would be 'players succeed if they are natural born athletes'.

Table 7.9 Results of the Beliefs about the Causes of Success Questionnaire (BASQ) for Elite and Non-Elite adolescent female sports performers (mean ± SEM)

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean</th>
<th>SEM</th>
<th>N</th>
<th>Sig</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BASQ - EFFORT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite Athletes</td>
<td>4.28</td>
<td>0.05</td>
<td>66</td>
<td></td>
<td>NS</td>
</tr>
<tr>
<td>Non-Elite Athletes</td>
<td>4.29</td>
<td>0.07</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>4.28</td>
<td>0.04</td>
<td>126</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>BASQ - ABILITY</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite Athletes</td>
<td>3.45</td>
<td>0.08</td>
<td>66</td>
<td></td>
<td>NS</td>
</tr>
<tr>
<td>Non-Elite Athletes</td>
<td>3.46</td>
<td>0.09</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3.46</td>
<td>0.06</td>
<td>126</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
7.4.4 Situational Motivation Scale (SIMS)

Table 7.10 shows the results of the Situational Motivation Scale. The elite athletes were significantly (P<0.05) less likely to show a high intrinsic motivation for their participation in sport than were the non-elite athletes. There were no significant differences between the groups for any of the other constructs within this scale. A typical response to the question ‘why are you currently engaged in playing/taking part in your sport?’ for the intrinsic motivation construct would be ‘because I think my sport is interesting’; for the identified regulation construct a typical response to the same question would be ‘because I am doing it for my own good’; for the external regulation construct a typical question would be ‘because it is something I have to do’, and for the amotivation construct a typical question would be ‘there may be reasons to play my sport, but personally I don’t see them’.

Table 7.10 Results of the Situational Motivation Scale for Elite and Non-Elite adolescent female sports performers (mean ± SEM)

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean</th>
<th>SEM</th>
<th>N</th>
<th>Sig</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SIMS Intrinsic Motivation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite Athletes</td>
<td>5.68</td>
<td>0.16</td>
<td>65</td>
<td>P&lt;0.05</td>
<td>.42</td>
</tr>
<tr>
<td>Non-Elite Athletes</td>
<td>6.10</td>
<td>0.13</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>5.88</td>
<td>0.11</td>
<td>125</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SIMS Identified Regulation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite Athletes</td>
<td>5.77</td>
<td>0.15</td>
<td>65</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>Non-Elite Athletes</td>
<td>5.82</td>
<td>0.15</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>5.79</td>
<td>0.10</td>
<td>125</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SIMS External Regulation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite Athletes</td>
<td>2.07</td>
<td>0.16</td>
<td>65</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>Non-Elite Athletes</td>
<td>1.85</td>
<td>0.18</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1.96</td>
<td>0.12</td>
<td>125</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SIMS Amotivation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite Athletes</td>
<td>2.03</td>
<td>0.15</td>
<td>65</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>Non-Elite Athletes</td>
<td>1.78</td>
<td>0.15</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1.91</td>
<td>0.11</td>
<td>125</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
7.4.5 Perceptions of Success Questionnaire (POSQ)

Table 7.11 shows the results of the perceptions of success questionnaire for elite and non-elite girls. There were no significant differences between the groups for either task or ego orientation. A typical response to the statement 'when playing/competing in competitions in my sport I feel most successful when:' for the task construct would be ‘I try hard’, and for the ego construct would be ‘I beat other people’.

<table>
<thead>
<tr>
<th>Table 7.11 Results of the Perception of Success Questionnaire for Elite and Non-Elite adolescent female sports performers (mean ± SEM)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group</strong></td>
</tr>
<tr>
<td><strong>POSQ Task</strong></td>
</tr>
<tr>
<td>Elite Athletes</td>
</tr>
<tr>
<td>Non-Elite Athletes</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td><strong>POSQ Ego</strong></td>
</tr>
<tr>
<td>Elite Athletes</td>
</tr>
<tr>
<td>Non-Elite Athletes</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>
7.5 Discussion
The main findings for this study were that in the Test of Performance Strategies the elite girls were significantly more likely to use the psychological skill of imagery \((P<0.01)\) and to be able to concentrate \((P<0.01)\) during practice than the non-elite girls. During competition the elite girls were significantly more likely to use the psychological skill activation \((P<0.05)\), also known as 'psyching up' and significantly more likely to employ goal-setting \((P<0.01)\) than the non-elite girls.

There were few differences in psychological skills usage in either practice or competition between the elite and non-elite adolescent female athletes in this study when the Test of Performance Strategies instrument was analysed. This may have been due to the relative youth of the participants. As the athletes become more mature and more experienced their psychological skill set should enlarge, particularly for the elite athletes as they engage in more and more deliberate practice. Ericsson and Charness (Ericsson et al., 1993; Ericsson and Charness, 1994) emphasize the importance of motivation and effort in the acquisition of expert performance in any domain, be it sport, chess, music, or the visual arts. Winning international competitions in sports, arts or sciences appears to take ten years or more of development and preparation, sometimes a lot longer (2004). Istvan Balyi (2002) further defined this period as ten years, or ten thousand hours, which is around three hours training a day. Coaches can use Test of Performance Strategy scores to provide information about existing psychological skills possessed by the athlete and those that the athlete needs for future success, however this is a self-report instrument and is thus it is open to an athlete deciding to 'skew' the results in their (perceived) favour, particularly if the instrument is used regularly. The role of the coach in the education of their athletes in sport psychology skills is important and it is critical that coaches are thoroughly educated in the use and application of psychological skills training.

Gould et al. (2002) found that a number of Olympic Champion athletes who participated in a psychological profiling study with them exhibited the following characteristics "a) the ability to cope with and control anxiety; b) confidence; c) mental toughness/resilience; d) sport intelligence; e) the ability to focus and block out distractions; f) competitiveness; g) a hard-work ethic; h) the ability to set and achieve
goals; i) coachability; j) high levels of dispositional hope; k) optimism; and l) adaptive perfectionism" (Gould et al., 2002). These same individuals also revealed that their psychological development was influenced by a number of different people and institutions, including their families, the community, themselves, people from outside the sport, others from within sport and the sport process as a whole. The most important of these were the influences from the family and the coach (Thomas et al., 1999). The fact that our young athletes, many of whom may only be half way into their ten year development process, do not yet possess a full set of psychological skills that are significantly stronger than the non-elite athletes indicates one of two things, either the elite athletes are slowly assimilating and learning (whether subconsciously or consciously) the psychological skills needed to perform on an elite international stage, but not yet using them all or, the non-elite athletes are almost equally skilled in the use of the psychological skills delineated by the Test of Performance Strategies.

The psychological skills, as identified by the Test of Performance strategies (Thomas et al., 1999; Boucher, 2002), that the young elite athletes in the current study used significantly more in practice than the non-elite athletes were attentional control and imagery. Attentional control refers to the ability to focus, or concentrate, attention on the task in hand and to use either controlled or automatic processing to perform at the necessary level and to block out external or internal distractions; attentional control is a central factor in cognitive sport psychology (2002). The elite athletes in the current study were demonstrating use of an important psychological skill that will enable them to improve their chances in competition by improving the outcomes of their practice sessions. In order to improve their sport skills the elite athletes are deliberately concentrating in practice. This was one of the key skills that Gould et al. (1988) found characterised the Olympic Champions in their study. Gould et al., (2002) hypothesised that, based on research in other areas of psychology, Olympic Champions would demonstrate high scores if they completed the Test of Performance Strategies instrument. Orlick and Partington (Thomas et al., 1999; Murphy and Martin, 2002) also studied Olympic athletes and found that virtually all of their subjects used mental skills as part of their preparation, particularly focus.
Chapter 7  Psychological Determinants

The elite athletes also used imagery in practice significantly more than the non-elite athletes. Imagery is a construct that researchers agree is an important psychological skill in sport (Thomas et al., 1999; Murphy and Martin, 2002), and that it is a skill that can be practiced and improved (Orlick, 1990). The young elite girls in the present study are using this skill in practice during adolescence and as they progress through their athletic careers they may start to use this skill more and more during competition to produce optimal performances. Imagery is an activity that requires full concentration from the athlete in order for them to be able to create and control images (Orlick and Partington, 1988; Gould et al., 2002). Olympic athletes report having well developed imagery skills and using them daily in practice and in competition (2002). Cumming et al., (2002) suggest that swimmers with moderate to high task and high ego orientations used more motivational specific imagery than those swimmers who displayed moderate task/low ego orientations and those who displayed low task/moderate ego orientations.

During competition the elite girls were using the psychological skills of activation (‘psyching up’) and goal-setting significantly more than the non-elite girls. Activation refers to the raising (to optimal levels) of psychological and physiological energy, the increase in the level of arousal in preparation for intense and vigorous activity, almost the direct opposite of relaxation which is generally viewed as a separate skill (1988). Orlick and Partington (2001) found that Olympic athletes they interviewed all had mental preparation strategies or ‘focus plans’ which they used both in training and in competition. These ‘focus plans’ are definable as plans for activation on both practice and in competition coupled with distraction control techniques. Williams and Krane (Orlick and Partington, 1988; Orlick, 1990; Williams and Krane, 2001; Gould et al., 2002) stated that having the ability to self-regulate arousal and having the necessary coping skills to deal with distractions and unexpected events are two key psychological characteristics of elite sports performers.

The elite athletes were also significantly more likely to use goal-setting in competition than the non-elite athletes. Goal-setting is a key skill frequently cited as being a key psychological characteristic of an elite performer (Orlick and Partington, 1988; Williams and Krane, 2001; Gould, 2002). Goal-setting is a psychological skill that is widely used by coaches to motivate their athletes, both in training and in competition. Goal-setting
and imagery skills are very useful for an athlete to use to productively manage their anxiety levels.

The results of the Performance Player Profile instrument are broadly categorised into either task or ego oriented constructs applied to coaches, fathers, mothers, peers and significant others, as perceived by the athlete. Gould et al. (2002) found that Olympic Champions felt that their psychological development had been highly influenced by family, friends, peers, coaches, the local community, and sport environment personal, in particular their family and coaches. This is borne out by the results of the Performance Player Profile which finds that the elite girls in the current study feel that their coaches, fathers, and peers are all more likely to be engaging in or displaying, task involving values/attitudes/behaviours than the coaches, fathers and peers of the non-elite girls. The coaches, fathers and mothers of the elite girls also were more likely than the coaches, fathers and mothers of the non-elite athletes to engage in or display ego involving behaviours. The elite athletes felt that their peers were more likely to display task involving values and behaviours. How the elite athletes perceived the values and attitudes of significant people in their sporting spheres is likely to have a strong impact on their reactions to them. Harwood et al. (2005) felt that the "impacts of these social agents on the individual athlete's competition environment cannot be over-estimated" (Harwood et al., 2005). When asked how they felt significant others had affected their thoughts, feelings and behaviour in competition the elite athletes were significantly more likely to feel that they had been influenced by these people. If an athlete perceives that their parents or coaches believe that effort leads to success this is likely to be related to the athletes' task orientation and personal belief that effort causes sport success (White et al., 2004).

The Situational Motivation Scale showed that the elite athletes in this study appeared to be significantly less intrinsically motivated than the non-elite athletes. It is arguable that by the time an athlete is an elite athlete that they are no longer taking part in a sport for the pure joy of taking part and that other factors have now come into play. The non-elite athletes are still enjoying their sport simply for the pleasure and satisfaction derived from performing (White et al., 2004), in other words they are taking part in the sport for themselves. Surprisingly there were no significant findings for either of the
extrinsic motivational subscales. Equally surprisingly there were no significant differences between the elite and non-elite athletes in the Beliefs About the Causes of Success Questionnaire, which fed into sub-scales of Effort and Ability. The fact that there were no significant differences between the elite and non-elite girls for either task or ego orientation when analysed using the Perceptions of Success Questionnaire or effort and ability for the Beliefs About the Causes of Success Questionnaire suggests that either the instruments are not sufficiently sensitive for girls of this age group or, that the non-elite girls and the elite girls are homogenous in their psychological makeup, as the participants in the current study were all active in sports at either elite or non-elite level. It maybe that the differentiation between the groups was not wide enough to allow any differences to be displayed. Many of the non-elite girls in this study were actively training and competing at their chosen sport at school and local level.

7.6 Conclusion
In conclusion, this study found that the elite female adolescent sports performer did make wider use of psychological skills in training/practice than their non-elite counterparts, when examined using the Test of Performance Strategies. The elite girls perceived a higher task and ego orientation in their coaches, fathers, mothers and peers than the non-elite girls, which reflects on their own task and ego orientations when they completed the Performance Player Profile (still under validation), although these findings were not echoed in the results of the Beliefs About the Causes of Success Questionnaire or in the results of the Perceptions of Success Questionnaire where the elite and non-elite girls had very similar scores. This may be an effect of the homogenous nature of the two groups of athletes, both of whom were training and competing regularly, albeit at differing levels.
A mixed longitudinal analysis of the effect of growth and maturation on the performance of female adolescent elite and non-elite sports performers.

8.1 Introduction

The areas of interest delineated in the preceding chapters were all examined as cross-sectional studies. However, when the cohort in question is made up of adolescents the snapshot effect of a cross-sectional study is far more pronounced than if the cohort were comprised of adults, as a repeat of the experimental condition will be clouded by the growth and maturational changes over time of the adolescent sports performers. Adolescence is a period of tremendous changes in body size, body composition, and the development of adult sexual characteristics (Beunen and Malina, 1988). The rate and tempo of these changes vary from person to person and can affect their performance in sports (Beunen and Malina, 1988). In order to most effectively measure the effects of growth and maturation on performance it is necessary to conduct a longitudinal (repeated measures) study. The use of statistical ‘scaling’ procedures, such as multi-level regression modelling, which remove the effects of body size on exercise performance, makes longitudinal studies investigating the effects of growth and maturation on the performance of a specific population a very useful tool for the researcher in this area (Welsman and Armstrong, 2000b).

There are few studies that have investigated the differences in performance in relation to growth and maturation between elite and non-elite sports performers, and even fewer that have investigated female elite and non-elite sports performers longitudinally. The Training of Young Athletes (TOYA) study (Baxter-Jones et al., 1993; Maffulli et al., 1994b; Baxter-Jones et al., 1994; Baxter-Jones et al., 1995; Baxter-Jones and Helms, 1996; Erlandson et al., 2008) investigated the effects of anthropometric changes and sexual maturation in a large cohort (n=453) of young elite male (n=231) and female
(n=222) athletes from gymnastics, soccer, and swimming for a period of approximately 3.5 years. In brief, the TOYA study found that female gymnasts were shorter than tennis players and swimmers at all chronological ages during adolescence and had a later menarche than the swimmers and tennis players, but that there were no differences in adult heights between the groups, suggesting that regular training did not affect final stature and that, when aligned by biological age, the tempo of sexual maturation was similar in the young athletes of the TOYA study (Erlandson et al., 2008). An examination of the effects of training in the TOYA study found that the athletic children were able to exert greater isometric strength than normal school children and that the athletic girls were stronger at all ages, whilst the boys diverged from the normal population at 14 years. Girls were stronger than boys up to age 12. Boys increased their strength up to 19 years. Male gymnasts over 11 years were stronger than all the other athletes. The rate of injuries in the studied population was low during the period examined (Maffulli et al., 1994a; Baxter-Jones and Helms, 1996). A study of the growth and development of the male athletes in the TOYA study revealed that the gymnasts were late maturers, whilst the swimmers were early maturers and that regular training did not appear to have affected the growth and development of the athletes in the study (Baxter-Jones et al., 1995; Baxter-Jones and Helms, 1996). The development of aerobic power in the young athletes of the TOYA study was also examined and found that when age, height and body mass were controlled for, $\dot{V}O_2$ max in males increased with maturation and that, with the exception of the male gymnasts, that the $\dot{V}O_2$ max increased with chronological age. The male swimmers had higher levels of $\dot{V}O_2$ max than the participants in the other 3 sports (gymnastics, tennis, football). The study found that the swimmers, tennis players and footballers all had higher values of $\dot{V}O_2$ max (when expressed as ml.kg$^{-1}$.min$^{-1}$) at all stages of pubertal development than a population of normal untrained British children. The female athletes showed a similar pattern of increasing $\dot{V}O_2$ max with maturation, though the significant increase in $\dot{V}O_2$ max during the later stages of maturation shown in the male athletes was not shown in the females (Baxter-Jones et al., 1993).

Welsman and Armstrong (2000a) investigated the changes in submaximal oxygen uptake in a large cohort of untrained young boys (n=118) and girls (n=118)
longitudinally for a period of three years and, using multilevel regression modelling
found that submaximal \( \dot{V}O_2 \) responses were explained predominantly by changes in
body mass and skinfold thicknesses and that there was no effect of maturity in this
population (Welsman and Armstrong, 2000a).

Following on from the studies in this thesis which are based on cross-sectional data, it is
hypothesised that the longitudinal studies of the female elite adolescent sport performer
will differentiate between the effects of training and genetics on the age and maturity
associated variation in the longitudinal development of physiological characteristics in
female elite and non-elite adolescent sports performers using a multi-level modelling
approach. As a result of the very limited number of longitudinal studies in this area the
hypothesis for the present study is based largely on cross-sectional data. Thus, the
differences between the elite female adolescent sport performer and her non-elite peers
in peak \( \dot{V}O_2 \) (ml.kg\(^{-1}\).min\(^{-1}\)), Running economy (ml.kg\(^{-1}\).min\(^{-1}\)), Blood lactate
concentrations, 30 s maximal cycle sprint peak power outputs, and strength measures
will reflect the training status of the elite female adolescent sports performer in addition
to any genetic effects.

8.2 Methods

8.2.1 Participants

Eighty six elite and 100 non-elite female adolescent sports performers aged from 11.9 to
16.1 and 11.7 to 15.5 (elite and non-elite respectively) at their first visit, agreed to
participate. The athletes came in to the laboratory approximately every 6 months. The
athletes always attended in groups of 2 or 3 athletes from the same school. They would
be collected from either home or school and brought to laboratory for a 9 am start. The
same timetable for testing was followed on every testing occasion. As with all
longitudinal studies some drop-out was experienced; of the initial one hundred and
eighty six participants one hundred and forty two did not return for further testing either
through choice or due to injury.
The number of visits made to the laboratory by the participants is detailed in Table 8.1 below.

Table 8.1 The number of visits to the laboratory for testing made by female elite and non-elite adolescent sports performers.

<table>
<thead>
<tr>
<th>Visits to the Laboratory</th>
<th>Elite</th>
<th>Non-Elite</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 visit only</td>
<td>55</td>
<td>87</td>
<td>142</td>
</tr>
<tr>
<td>2 visits</td>
<td>11</td>
<td>5</td>
<td>16</td>
</tr>
<tr>
<td>3 visits</td>
<td>11</td>
<td>6</td>
<td>17</td>
</tr>
<tr>
<td>4 visits</td>
<td>9</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>5 visits</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>86</strong></td>
<td><strong>100</strong></td>
<td><strong>186</strong></td>
</tr>
</tbody>
</table>

8.2.2 Physical characteristics

Chronological age was calculated as the difference between the date of testing and the date of birth of the participant and was expressed as decimal age. Stature was measured to the nearest 0.1cm and body mass to the nearest 0.1kg. Skinfold thickness for the determination of adiposity was measured at seven sites: triceps, biceps, subscapular, supraspinale, abdominal, anterior thigh, and medial calf. The mean value of three measurements at each site was then summed and used to calculate the sum of either all seven skinfolds, or the sum of four skinfolds, namely triceps, biceps, subscapular and supraspinale. A more detailed account of this procedure can be seen in Chapter 3 section 3.3.3. All participants were asked to perform a self-assessment of secondary sexual characteristics according to Tanner’s (1962) indices of secondary sexual characteristics. A more detailed account of this procedure can be seen in Chapter 3 section 3.3.2. Each participant was thoroughly familiarised with treadmill walking and running (for a more detailed account of this procedure see Chapter 3 section 3.4.2 & 3.4.3). A resting finger tip capillary blood sample was collected for determination of resting blood lactate concentration (mmol.l⁻¹) by the fluourometric method (Maughan, 1982).
8.2.3 Main laboratory tests

The participants had a finger-prick blood sample taken for the later determination of resting blood lactate concentration prior to performing a submaximal incremental treadmill test, full details of which can be found in Chapter 3, section 3.5. The test consisted of 4 min incremental stages at treadmill running speeds of 8, 9, 10, and 12 km.h\(^{-1}\), with no incline. Expired air samples were collected during the 4\(^{th}\) min of exercise at each speed (Chapter 3 section 3.4.3). Heart rate (beats.min\(^{-1}\)) was continuously recorded using short range telemetry and recorded every 15 s during each collection period. Participant’s rating of perceived exertion (RPE) was also recorded towards the end of each collection period using the Borg scale (Borg, 1982). At the end of each 4 min stage the participant jumped onto the side bars of the treadmill for 30 s to enable finger prick blood samples to be taken for the later determination of blood lactate concentration.

After resting the participants then performed a continuous progressive, incremental uphill treadmill test to voluntary exhaustion to determine peak \(\dot{VO}_2\) see Chapter 3 section 3.4.4. The treadmill remained at a constant speed throughout the test. This speed was determined by the researcher and was chosen because it elicited a heart rate of approximately 170 beats.min\(^{-1}\) during the earlier submaximal treadmill test see Chapter 3 section 3.4.3, and was anticipated to elicit voluntary exhaustion between 8 and 12 min from the start of the test. The treadmill test commenced with an incline of 3\% which was increased by 2\% every 3 min. Expired air samples using the Douglas bag method were taken during the test 1:45 – 2:45 min into each 3 min stage. Heart rate (beats.min\(^{-1}\)) was continuously monitored throughout the test. Participants ran until they indicated that they could exercise for 60 s and no longer. At this point the final expired air collection was made and the test ended. Strong verbal encouragement was given throughout the test. Peak \(\dot{VO}_2\) was regarded as that achieved during the last min of the test and was deemed to have occurred when at least two of the following criteria were achieved: a) peak recorded heart rate was greater than 95\% of age predicted maximum (220 – age); b) a peak respiratory exchange ratio value (RER) of greater than unity; c) subjective signs of fatigue, e.g. inability to keep pace with the treadmill, facial flushing, hyperpnoea, dyspnoea, and unsteady gait.
The participants then had lunch and at least one hour of rest before commencing the afternoon testing.

The participants had finger-prick capillary blood samples taken in duplicate, for the later determination of resting blood lactate concentration, prior to being familiarised with the 30 s Maximal Cycle Ergometer Sprint procedure as detailed in Chapter 3, section 3.4.6. Briefly, all participants completed a standardised warm-up consisting of cycling for 30 s at 80 rev.min\(^{-1}\), followed by 30 s rest and then a further 30 s cycling at 110 rev.min\(^{-1}\), all against 1 kg resistive mass. Five minutes after completion of the warm-up the participants performed a maximal 30 s cycle sprint from a rolling start of 60 rev.min\(^{-1}\) against a resistive mass of 0.07 kg.kg\(^{-1}\) body mass. Strong verbal encouragement was given throughout the duration of the test. The power output was calculated for each second of the duration of the test. The peak power over one second and the mean power over the whole 30 s period were recorded. Fatigue index was also calculated from the difference in peak power and the lowest power output value (100 / peak power output x lowest power output). All procedures were undertaken as described by Lakomy (1982). Finger-prick capillary blood samples for the later determination of blood lactate concentration were taken at 3 min post warm-up and at 2 min post sprint and at 5 min post sprint (Chapter 3, Section 3.5).

After a rest period the participants were then instructed in the use of the Concept2 Dyno® as detailed in Chapter 3 section 3.4.7. The participants had 3 warm-up pushes or pulls followed by three best effort pushes or pulls of which the best score was recorded.

8.2.4 Blood sampling and analysis

The blood sampling, collection, treatment and storage procedures used in this study are described in detail in Chapter 3 section 3.5. Briefly, duplicate 20μl capillary blood samples were collected from finger-tips at the end of each stage of the submaximal incremental treadmill test, and also during the 30 s cycle sprint at 3 min post warm-up and at 2 min and 5 min post sprint and were later analysed for lactate using the fluorometric method (Maughan, 1982).
8.2.5 Statistical Analyses

This data set is longitudinal which makes it appropriate to use multi-level modelling to analyse the differences between the elite and non-elite female adolescent athletes over time. Multilevel modelling is an extension of multiple regression and is suitable for longitudinal hierarchically structured data. In such data sets the data consists of the repeated measurement occasions defined as \textit{level 1} units, which are grouped within an individual participant (\textit{level 2} units). The individuals are assumed to be a random sample, and also the number of measurement occasions is also assumed to be a random variable over time. The two levels of random variation account for the differences in the individuals growth characteristics around the population mean and also variation in their own growth trajectory. In this thesis differences between the elite and non-elite female adolescent athletes in the development of peak $\dot{V}O_2$ and short-term power, and heart rate responses, percentage of maximal heart rate and blood lactate concentrations during submaximal treadmill running were examined using the multilevel modelling program MLwiN 2.10 (Rasbash et al., 2005). A linear additive multilevel model structure was employed. Two levels of hierarchical observational units were the number of visits at level 1 (within individuals) and the sample of adolescents (between individuals) at level 2.

All parameters were fixed, apart from the constant parameter, which was allowed to vary randomly between individuals (\textit{level 2}), and within individuals, between testing occasions (\textit{level 1}). The characteristics and performance of the non-elite group was used as a baseline parameter with which the performance of the elite group was compared, i.e. allowed to deviate from the baseline. In addition, a Binary Logistic Regression was used to identify which characteristics distinguished the elite performers from the non-elite performers MLwiN 2.10 (Rasbash et al., 2005).
8.3 Results

8.3.1 Physical Characteristics

Table 8.2 shows the year-by-year changes in physical characteristics of elite and non-elite adolescent female athletes.
Table 8.2 Physical characteristics of the female elite and non-elite adolescent sports performers between 12 and 16 years of age (mean ± SEM)

<table>
<thead>
<tr>
<th>Age (yrs)</th>
<th>Elite</th>
<th>Non-Elite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12.8 ± 0.1 (n=86)</td>
<td>12.6 ± 0.1 (n=100)</td>
</tr>
<tr>
<td></td>
<td>13.5 ± 0.1 (n=5)</td>
<td>13.5 ± 0.01 (n=18)</td>
</tr>
<tr>
<td></td>
<td>14.5 ± 0.0 (n=25)</td>
<td>14.5 ± 0.1 (n=27)</td>
</tr>
<tr>
<td></td>
<td>15.5 ± 0.0 (n=38)</td>
<td>15.5 ± 0.0 (n=26)</td>
</tr>
<tr>
<td></td>
<td>16.6 ± 0.1 (n=44)</td>
<td>16.6 ± 0.1 (n=36)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Elite</th>
<th>Non-Elite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.56 ± 0.01 (n=86)</td>
<td>1.61 ± 0.02 (n=100)</td>
</tr>
<tr>
<td></td>
<td>1.62 ± 0.01 (n=5)</td>
<td>1.63 ± 0.01 (n=18)</td>
</tr>
<tr>
<td></td>
<td>1.67 ± 0.01 (n=25)</td>
<td>1.64 ± 0.01 (n=27)</td>
</tr>
<tr>
<td></td>
<td>1.66 ± 0.01 (n=38)</td>
<td>1.64 ± 0.01 (n=26)</td>
</tr>
<tr>
<td></td>
<td>1.69 ± 0.01 (n=44)</td>
<td>1.65 ± 0.01 (n=36)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Body Mass (kg)</th>
<th>Elite</th>
<th>Non-Elite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>41.6 ± 2.1 (n=86)</td>
<td>48.9 ± 2.1 (n=100)</td>
</tr>
<tr>
<td></td>
<td>51.4 ± 2.0 (n=5)</td>
<td>53.1 ± 1.9 (n=18)</td>
</tr>
<tr>
<td></td>
<td>55.0 ± 1.4 (n=25)</td>
<td>56.0 ± 1.8 (n=27)</td>
</tr>
<tr>
<td></td>
<td>56.4 ± 1.3 (n=38)</td>
<td>56.0 ± 1.1 (n=26)</td>
</tr>
<tr>
<td></td>
<td>60.4 ± 1.6 (n=44)</td>
<td>58.4 ± 1.9 (n=36)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sum of 4 Skinfolds (mm)</th>
<th>Elite</th>
<th>Non-Elite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25.2 ± 3.3 (n=86)</td>
<td>36.8 ± 3.0 (n=100)</td>
</tr>
<tr>
<td></td>
<td>42.9 ± 4.3 (n=5)</td>
<td>48.5 ± 4.3 (n=18)</td>
</tr>
<tr>
<td></td>
<td>40.1 ± 2.2 (n=25)</td>
<td>50.6 ± 3.0 (n=27)</td>
</tr>
<tr>
<td></td>
<td>42.2 ± 2.3 (n=38)</td>
<td>48.9 ± 2.6 (n=26)</td>
</tr>
<tr>
<td></td>
<td>44.9 ± 3.2 (n=44)</td>
<td>51.0 ± 3.8 (n=36)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Estimated Percentage Body Fat (Lohman, 1982)</th>
<th>Elite</th>
<th>Non-Elite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>19.0 ± 1.5 (n=86)</td>
<td>23.3 ± 1.0 (n=100)</td>
</tr>
<tr>
<td></td>
<td>25.2 ± 1.3 (n=5)</td>
<td>26.2 ± 1.1 (n=18)</td>
</tr>
<tr>
<td></td>
<td>25.4 ± 0.8 (n=25)</td>
<td>28.2 ± 0.8 (n=27)</td>
</tr>
<tr>
<td></td>
<td>26.0 ± 0.8 (n=38)</td>
<td>29.5 ± 0.8 (n=24)</td>
</tr>
<tr>
<td></td>
<td>27.5 ± 1.0 (n=44)</td>
<td>29.5 ± 1.0 (n=33)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sexual Maturity – Pubic Hair Development</th>
<th>Elite</th>
<th>Non-Elite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.4 ± 0.2 (n=86)</td>
<td>3.1 ± 0.3 (n=100)</td>
</tr>
<tr>
<td></td>
<td>3.5 ± 0.2 (n=5)</td>
<td>3.5 ± 0.2 (n=16)</td>
</tr>
<tr>
<td></td>
<td>4.0 ± 0.1 (n=25)</td>
<td>4.3 ± 0.2 (n=24)</td>
</tr>
<tr>
<td></td>
<td>4.2 ± 0.1 (n=38)</td>
<td>4.3 ± 0.1 (n=26)</td>
</tr>
<tr>
<td></td>
<td>4.7 ± 0.1 (n=44)</td>
<td>4.4 ± 0.2 (n=36)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sexual Maturity – Breast Development</th>
<th>Elite</th>
<th>Non-Elite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.8 ± 0.4 (n=86)</td>
<td>3.2 ± 0.2 (n=100)</td>
</tr>
<tr>
<td></td>
<td>3.5 ± 0.2 (n=5)</td>
<td>4.0 ± 0.2 (n=17)</td>
</tr>
<tr>
<td></td>
<td>4.0 ± 0.1 (n=23)</td>
<td>4.3 ± 0.1 (n=27)</td>
</tr>
<tr>
<td></td>
<td>4.3 ± 0.1 (n=36)</td>
<td>4.2 ± 0.1 (n=26)</td>
</tr>
<tr>
<td></td>
<td>4.7 ± 0.1 (n=40)</td>
<td>4.4 ± 0.1 (n=36)</td>
</tr>
<tr>
<td></td>
<td>(n=25)</td>
<td>(n=17)</td>
</tr>
</tbody>
</table>
Table 8.3 shows the year-by-year changes in peak cardiopulmonary responses for female elite and non-elite adolescent athletes.

Table 8.3  Peak cardiopulmonary responses in female elite and non-elite adolescent sports performers between 12 and 16 years of age (mean ± SEM)

<table>
<thead>
<tr>
<th>Age (yrs)</th>
<th>Elite n=86</th>
<th>Non-Elite n=100</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n=5)</td>
<td>(n=18)</td>
</tr>
<tr>
<td><strong>Peak (\dot{V}O_2) (ml.kg(^{-1}).min(^{-1}))</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite n=86</td>
<td>12.8 ± 0.1</td>
<td>13.5 ± 0.1</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>12.6 ± 0.1</td>
<td>13.5 ± 0.01</td>
</tr>
<tr>
<td>n=100</td>
<td>(n=18)</td>
<td>(n=27)</td>
</tr>
<tr>
<td><strong>Peak (\dot{V}O_2) (l.min(^{-1}))</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite n=86</td>
<td>2.11 ± 0.18</td>
<td>2.49 ± 0.07</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>2.18 ± 0.09</td>
<td>2.36 ± 0.07</td>
</tr>
<tr>
<td>n=100</td>
<td>(n=17)</td>
<td>(n=27)</td>
</tr>
<tr>
<td><strong>Peak Heart Rate (beats.min(^{-1}))</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite n=86</td>
<td>203 ± 3</td>
<td>199 ± 1</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>203 ± 3</td>
<td>199 ± 1</td>
</tr>
<tr>
<td>n=100</td>
<td>(n=17)</td>
<td>(n=27)</td>
</tr>
<tr>
<td><strong>Respiratory Exchange Ratio (R)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elite n=86</td>
<td>1.07 ± 0.03</td>
<td>1.08 ± 0.01</td>
</tr>
<tr>
<td>Non-Elite</td>
<td>1.08 ± 0.02</td>
<td>1.07 ± 0.01</td>
</tr>
<tr>
<td>n=100</td>
<td>(n=17)</td>
<td>(n=27)</td>
</tr>
</tbody>
</table>
Linear additive regression analysis showed that Peak $\dot{V}O_2$ (ml.kg\(^{-1}\).min\(^{-1}\)) was higher in the elite female adolescent athletes, by 3.9 ml.kg\(^{-1}\).min\(^{-1}\), compared to the Peak $\dot{V}O_2$ seen in the non-elite athletes ($P<0.05$) (Table 8.4). There was an additive effect of maturation at GB (breast development) stage 4 of 1.2 ml.kg\(^{-1}\).min\(^{-1}\). Sum of skinfolds also influenced the Peak $\dot{V}O_2$ such that each 10mm increase in the sum of 4 skinfolds resulted in a 1.5ml decrease in Peak $\dot{V}O_2$.

Table 8.4: Multilevel regression analysis of peak oxygen uptake (ml.kg\(^{-1}\).min\(^{-1}\)) in elite and non-elite females

<table>
<thead>
<tr>
<th>Fixed Explanatory Variables</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>51.321 ± 1.206</td>
</tr>
<tr>
<td>Elite ($\Delta$)</td>
<td>3.923 ± 0.738</td>
</tr>
<tr>
<td>Maturation – Girls breast development stage 4</td>
<td>1.216 ± 0.550</td>
</tr>
<tr>
<td>Sum of 4 skinfolds (mm)</td>
<td>-0.154 ± 0.022</td>
</tr>
</tbody>
</table>

The variance of the random variable (constant)

- **Level 1 (within individuals)**
  - Constant: 9.611 ± 1.499

- **Level 2 (between individuals)**
  - Constant: 11.097 ± 2.405
  - $-2 \times \log$ likelihood: 1270.532

Values are means ± SEE (Standard Error of the Estimate). Non-elite females were used as a baseline with the elite females compared to it, indicated by ($\Delta$).

Therefore the prediction equations to calculate peak oxygen uptake (ml.kg\(^{-1}\).min\(^{-1}\)) are for:

**Elite females:**
- In stage 4
  - Peak Oxygen Uptake (ml.kg\(^{-1}\).min\(^{-1}\)) = 51.321 + 3.923 + 1.216 - 0.154. Sum of 4 skin folds (mm)

**Elite females:**
- Not in stage 4
  - Peak Oxygen Uptake (ml.kg\(^{-1}\).min\(^{-1}\)) = 51.321 + 3.923 - 0.154. Sum of 4 skin folds (mm)

**Non-elite females:**
- In stage 4
  - Peak Oxygen Uptake (ml.kg\(^{-1}\).min\(^{-1}\)) = 51.321 + 1.216 - 0.154. Sum of 4 skin folds (mm)

**Non-elite females:**
- Not in stage 4
  - Peak Oxygen Uptake (ml.kg\(^{-1}\).min\(^{-1}\)) = 51.321 - 0.154. Sum of 4 skin folds (mm)
The natural logarithm (ln) for peak oxygen uptake (L.min⁻¹) in elite and non-elite female adolescent athletes are shown in table 8.5. Peak VO₂ (L.min⁻¹) was 10% higher in the elite athletes compared with the non-elite athletes (P<0.05). There was an additive effect of maturation in GB stage 4, such that athletes in GB stage 4 experienced a 3% improvement in peak VO₂. Both mass and height influenced peak VO₂ (P<0.05). The natural logarithm was used rather than raw data to correct for the fact that age and body mass and peak VO₂ are related but the relationships are not linear. In order to remove the confounding factors of age and body mass on peak oxygen uptake (L.min⁻¹) the natural logarithm (ln) for peak oxygen uptake (L.min⁻¹) was used.
Table 8.5  Multilevel regression analysis of the natural logarithm (ln) of peak oxygen uptake (l.min⁻¹) in elite and non elite females.

<table>
<thead>
<tr>
<th>Fixed Explanatory Variables</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-2.151 ± 0.202</td>
</tr>
<tr>
<td>Elite (Δ)</td>
<td>0.105 ± 0.018</td>
</tr>
<tr>
<td>Maturation – Girls breast development stage 4</td>
<td>0.026 ± 0.012</td>
</tr>
<tr>
<td>ln Mass (kg)</td>
<td>0.642 ± 0.064</td>
</tr>
<tr>
<td>ln Height (m)</td>
<td>0.909 ± 0.269</td>
</tr>
</tbody>
</table>

The variance of the random variable (constant)

<table>
<thead>
<tr>
<th>Level 1 (within individuals)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.004 ± 0.001</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level 2 (between individuals)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.008 ± 0.001</td>
</tr>
<tr>
<td>-2 x log likelihood</td>
<td>-414.102</td>
</tr>
</tbody>
</table>

Values are means ± SEE (Standard Error of the Estimate). Non elite females were used as a baseline with the elite females compared to it, indicated by (Δ).

Therefore the prediction equations to calculate peak oxygen uptake (l.min⁻¹) are for:

**Elite females:** In stage 4
Peak oxygen uptake (l.min⁻¹) = 0.133 . Mass (kg)⁰.⁶⁴² . Height (m)⁰.⁹⁰⁹

**Elite females:** Not in stage 4
Peak oxygen uptake (l.min⁻¹) = 0.129 . Mass (kg)⁰.⁶⁴² . Height (m)⁰.⁹⁰⁹

**Non elite females:** In stage 4
Peak oxygen uptake (l.min⁻¹) = 0.119 . Mass (kg)⁰.⁶⁴² . Height (m)⁰.⁹⁰⁹

**Non elite females:** Not in stage 4
Peak oxygen uptake (l.min⁻¹) = 0.116 . Mass (kg)⁰.⁶⁴² . Height (m)⁰.⁹⁰⁹
Table 8.6 displays the results of the submaximal treadmill test and related variables of the elite and non-elite female adolescent athletes at each year studied.

Table 8.6  
Heart rate (beats.min⁻¹), percentage of maximum heart rate (%), and blood lactate (mmol.l⁻¹) variables during submaximal treadmill running 9 km.h⁻¹ in female elite and non-elite adolescent sports performers between 12 and 16 years of age (mean ± SEM)

<table>
<thead>
<tr>
<th>Age (yrs)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite n=86</td>
<td>12.8 ± 0.1</td>
<td>13.5 ± 0.1</td>
<td>14.5 ± 0.0</td>
<td>15.5 ± 0.0</td>
</tr>
<tr>
<td>(n=5)</td>
<td>(n=25)</td>
<td>(n=38)</td>
<td>(n=44)</td>
<td>(n=33)</td>
</tr>
<tr>
<td>Non-Elite n=100</td>
<td>12.6 ± 0.1</td>
<td>13.5 ± 0.01</td>
<td>14.5 ± 0.1</td>
<td>15.5 ± 0.0</td>
</tr>
<tr>
<td>(n=18)</td>
<td>(n=27)</td>
<td>(n=26)</td>
<td>(n=36)</td>
<td>(n=18)</td>
</tr>
</tbody>
</table>

Heart Rate (beats.min⁻¹) at 9 km.h⁻¹

| Elite n=86 | 191 ± 2 | 176 ± 3 | 171 ± 2 | 172 ± 2 | 169 ± 2 |
| (n=5) | (n=24) | (n=36) | (n=40) | (n=25) |
| Non-Elite n=100 | 183 ± 4 | 184 ± 3 | 186 ± 3 | 188 ± 2 | 183 ± 2 |
| (n=16) | (n=21) | (n=25) | (n=34) | (n=18) |

Percentage of Maximum Heart Rate (%) at 9 km.h⁻¹

| Elite n=86 | 94 ± 1 | 88 ± 1 | 88 ± 1 | 87 ± 1 | 86 ± 1 |
| (n=5) | (n=24) | (n=36) | (n=37) | (n=24) |
| Non-Elite n=100 | 90 ± 1 | 92 ± 1 | 92 ± 1 | 93 ± 1 | 92 ± 1 |
| (n=16) | (n=20) | (n=24) | (n=33) | (n=17) |

Blood Lactate Concentration (mmol.l⁻¹) at 9 km.h⁻¹

| Elite n=86 | 3.66 ± 0.44 | 2.90 ± 0.39 | 3.14 ± 0.21 | 2.41 ± 0.18 | 2.97 ± 0.32 |
| (n=5) | (n=23) | (n=36) | (n=42) | (n=31) |
| Non-Elite n=100 | 2.49 ± 0.24 | 3.72 ± 0.34 | 3.56 ± 0.41 | 4.22 ± 0.31 | 4.19 ± 0.36 |
| (n=17) | (n=21) | (n=23) | (n=33) | (n=18) |
Chapter 8

Longitudinal Development

Linear additive multilevel regression analysis for heart rate (beats.min\(^{-1}\)) during submaximal treadmill running at 9 km.h\(^{-1}\) in elite and non-elite female adolescent athletes showed that heart rate was 12 beats.min\(^{-1}\) lower in the elite athletes when running submaximally at 9 km.h\(^{-1}\) (P<0.05) (Table 8.7). At maturation GB stage 4 the heart rate response to exercise was lower by 4 beats.min\(^{-1}\) (P<0.05). Sum of skinfolds also influenced the heart rate response such that each 10mm increase in the sum of 4 skinfolds resulted in a 2 beats.min\(^{-1}\) increase in the heart rate response to submaximal running at 9 km.h\(^{-1}\) (P<0.05).

Table 8.7 Multilevel regression analysis of heart rate (beats.min\(^{-1}\)) at 9 km.h\(^{-1}\) in elite and non elite females.

<table>
<thead>
<tr>
<th>Fixed Explanatory Variables</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>184.937 ± 3.3773</td>
</tr>
<tr>
<td>Elite (Δ)</td>
<td>-12.086 ± 2.103</td>
</tr>
<tr>
<td>Sum of 4 skinfolds (mm)</td>
<td>0.183 ± 0.063</td>
</tr>
<tr>
<td>Maturation – Girls breast development stage 3</td>
<td>-4.387 ± 2.355</td>
</tr>
<tr>
<td>Maturation – Girls breast development stage 4</td>
<td>-8.144 ± 2.451</td>
</tr>
<tr>
<td>Maturation – Girls breast development stage 5</td>
<td>-8.548 ± 2.693</td>
</tr>
</tbody>
</table>

The variance of the random variable (constant)

<table>
<thead>
<tr>
<th>Level 1 (within individuals)</th>
<th>Level 2 (between individuals)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>Constant</td>
</tr>
<tr>
<td></td>
<td>26.344 ± 4.551</td>
</tr>
<tr>
<td>-2 x log likelihood</td>
<td>-2 x log likelihood</td>
</tr>
<tr>
<td></td>
<td>122.765 ± 17.860</td>
</tr>
<tr>
<td></td>
<td>1509.301</td>
</tr>
</tbody>
</table>

Values are means ± SEE. Non elite females were used as a baseline with the elite females compared to it, indicated by (Δ).
The percentage of heart rate maximum (%) required to run at 9 km.h\(^{-1}\) was lower in the elite female athletes compared with the non-elite performers – 84% compared with 88% (P<0.05) (Table 8.8). The sum of skinfolds also influenced the proportion of maximum heart rate needed to run at 9 km.h\(^{-1}\); each 12mm increase in the sum of 4 skinfolds necessitated the utilisation of a further 1% of maximum heart rate.

Table 8.8  Multilevel regression analysis of percentage of maximum heart rate (%) at 9 km.h\(^{-1}\) in elite and non elite females.

<table>
<thead>
<tr>
<th>Fixed Explanatory Variables</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>88.198 ± 1.518</td>
</tr>
<tr>
<td>Sum of 4 skinfolds (mm)</td>
<td>0.078 ± 0.028</td>
</tr>
<tr>
<td>Elite</td>
<td>-4.126 ± 0.951</td>
</tr>
</tbody>
</table>

The variance of the random variable (constant)

<table>
<thead>
<tr>
<th>Level 1 (within individuals)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>6.536 ± 1.133</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level 2 (between individuals)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>24.023 ± 3.656</td>
</tr>
<tr>
<td>-2 x log likelihood</td>
<td>1199.212</td>
</tr>
</tbody>
</table>

Values are means ± SEE.
The blood lactate concentration seen in response to running at 9 km.h\(^{-1}\) was 1.5 (mmol.l\(^{-1}\)) lower in the elite athletes compared with the non-elite performers (P<0.05) (Table 8.9). There was an effect of age showing that as females get older blood lactate concentration (mmol.l\(^{-1}\)) increases.

**Table 8.9** Multilevel regression analysis of blood lactate concentration (mmol.l\(^{-1}\)) at 9 km.h\(^{-1}\) in elite and non-elite females.

<table>
<thead>
<tr>
<th>Fixed Explanatory Variables</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.461 ± 1.433</td>
</tr>
<tr>
<td>Elite (Δ)</td>
<td>-1.508 ± 0.265</td>
</tr>
<tr>
<td>Age (decimal years)</td>
<td>0.238 ± 0.098</td>
</tr>
</tbody>
</table>

The variance of the random variable (constant)

<table>
<thead>
<tr>
<th>Level 1 (within individuals)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.962 ± 0.164</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level 2 (between individuals)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>1.558 ± 0.306</td>
</tr>
<tr>
<td>-2 x log likelihood</td>
<td>726.322</td>
</tr>
</tbody>
</table>

Values are means ± SEE. Non-elite females were used as a baseline with the elite females compared to it, indicated by (Δ).
Table 8.10  Peak and mean power output and blood lactate variables during a 30 s maximal cycle ergometer sprint in female elite and non-elite adolescent sports performers between 12 and 16 years of age

Table 8.10 shows the results of the 30s maximal cycle sprint test and related variables of the elite and non-elite female adolescent athletes at each year studied (mean ± SEM).

<table>
<thead>
<tr>
<th>Age (yrs)</th>
<th>Elite</th>
<th>Non-Elite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n=86) (n=5)</td>
<td>(n=100) (n=17)</td>
</tr>
<tr>
<td>12.8 ± 0.1</td>
<td>13.5 ± 0.1</td>
<td>12.6 ± 0.1</td>
</tr>
<tr>
<td>13.5 ± 0.0</td>
<td>14.5 ± 0.0</td>
<td>13.5 ± 0.01</td>
</tr>
<tr>
<td>15.5 ± 0.0</td>
<td>15.5 ± 0.0</td>
<td>15.5 ± 0.0</td>
</tr>
<tr>
<td>16.6 ± 0.1</td>
<td>16.6 ± 0.1</td>
<td>16.6 ± 0.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Peak Power (W)</th>
<th>Elite</th>
<th>Non-Elite</th>
</tr>
</thead>
<tbody>
<tr>
<td>n=86 (n=5)</td>
<td>(n=100) (n=17)</td>
<td></td>
</tr>
<tr>
<td>366 ± 45</td>
<td>415 ± 21</td>
<td>440 ± 18</td>
</tr>
<tr>
<td>415 ± 21</td>
<td>471 ± 16</td>
<td>488 ± 18</td>
</tr>
<tr>
<td>471 ± 16</td>
<td>498 ± 17</td>
<td>478 ± 23</td>
</tr>
<tr>
<td>498 ± 17</td>
<td>580 ± 23</td>
<td>455 ± 18</td>
</tr>
<tr>
<td>580 ± 23</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Peak Power (W.kg⁻¹ FFM)</th>
<th>Elite</th>
<th>Non-Elite</th>
</tr>
</thead>
<tbody>
<tr>
<td>n=86 (n=5)</td>
<td>(n=100) (n=17)</td>
<td></td>
</tr>
<tr>
<td>10.75 ± 1.01</td>
<td>11.03 ± 0.45</td>
<td></td>
</tr>
<tr>
<td>10.73 ± 0.44</td>
<td>12.41 ± 0.36</td>
<td></td>
</tr>
<tr>
<td>11.44 ± 0.29</td>
<td>12.16 ± 0.40</td>
<td></td>
</tr>
<tr>
<td>11.93 ± 0.25</td>
<td>11.97 ± 0.43</td>
<td></td>
</tr>
<tr>
<td>12.73 ± 0.47</td>
<td>11.50 ± 0.32</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mean Power (W)</th>
<th>Elite</th>
<th>Non-Elite</th>
</tr>
</thead>
<tbody>
<tr>
<td>n=86 (n=5)</td>
<td>(n=100) (n=17)</td>
<td></td>
</tr>
<tr>
<td>260 ± 20</td>
<td>275 ± 11</td>
<td></td>
</tr>
<tr>
<td>290 ± 11</td>
<td>328 ± 11</td>
<td></td>
</tr>
<tr>
<td>337 ± 10</td>
<td>323 ± 13</td>
<td></td>
</tr>
<tr>
<td>355 ± 11</td>
<td>306 ± 11</td>
<td></td>
</tr>
<tr>
<td>399 ± 13</td>
<td>324 ± 16</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mean Power (W.kg⁻¹ FFM)</th>
<th>Elite</th>
<th>Non-Elite</th>
</tr>
</thead>
<tbody>
<tr>
<td>n=86 (n=5)</td>
<td>(n=100) (n=17)</td>
<td></td>
</tr>
<tr>
<td>7.70 ± 0.36</td>
<td>7.45 ± 0.19</td>
<td></td>
</tr>
<tr>
<td>7.69 ± 0.21</td>
<td>8.32 ± 0.17</td>
<td></td>
</tr>
<tr>
<td>8.25 ± 0.17</td>
<td>8.27 ± 0.19</td>
<td></td>
</tr>
<tr>
<td>8.59 ± 0.19</td>
<td>8.02 ± 0.29</td>
<td></td>
</tr>
<tr>
<td>8.82 ± 0.14</td>
<td>8.24 ± 0.25</td>
<td></td>
</tr>
</tbody>
</table>

203
The results of the linear additive multilevel regression analysis for the peak power output (W) from the 30 s maximal cycle sprints for elite and non-elite female adolescent athletes showed that there were no differences between the elite and non-elite athletes for peak power output (W), but that there was an effect of age and an effect of mass showing that older and heavier females had higher peak power outputs (W) (P<0.05) (Table 8.11). There was an effect of maturation at PH stage 5 for all participants showing that peak power output increases at this maturation stage (P<0.05). There was a negative effect of skinfolds showing that as skinfold thickness increases the peak power output (W) will go down (P<0.05).

Table 8.11 Multilevel regression analysis of peak power output (W) in elite and non-elite females.

<table>
<thead>
<tr>
<th>Fixed Explanatory Variables</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>445.153 ± 16.673</td>
</tr>
<tr>
<td>Age (Years) – gm (grand mean)</td>
<td>2.908 ± 5.293</td>
</tr>
<tr>
<td>Mass (kg) - gm</td>
<td>9.055 ± 0.960</td>
</tr>
<tr>
<td>Sum of 4 skinfolds (mm) - gm</td>
<td>-2.003 ± 0.500</td>
</tr>
<tr>
<td>Maturation – Pubic hair stage 3</td>
<td>-0.110 ± 17.238</td>
</tr>
<tr>
<td>Maturation – Pubic hair stage 4</td>
<td>32.961 ± 17.365</td>
</tr>
<tr>
<td>Maturation – Pubic hair stage 5</td>
<td>45.137 ± 19.842</td>
</tr>
</tbody>
</table>

The variance of the random variable (constant)

<table>
<thead>
<tr>
<th>Level 1 (within individuals)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>1788.211 ± 316.956</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level 2 (between individuals)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>3405.101 ± 642.632</td>
</tr>
<tr>
<td>-2 x log likelihood</td>
<td>1914.012</td>
</tr>
</tbody>
</table>

Values are means ± SEE.
Table 8.12 displays the results of the linear additive multilevel regression analysis for the peak power output (W.kg\(^{-1}\) FFM) from the 30 s maximal cycle sprints for elite and non-elite female adolescent athletes. There were no differences between the elite and non-elite groups for peak power output (W.kg\(^{-1}\) FFM) but there was an effect of maturation at PH stage 5 showing that peak power output (W) will increase at this maturation stage (P<0.05).

Table 8.12  Multilevel regression analysis of peak power output (watts.kg\(^{-1}\) FFM) in elite and non elite females.

<table>
<thead>
<tr>
<th>Fixed Explanatory Variables</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>10.825 ± 0.379</td>
</tr>
<tr>
<td>Maturation – Pubic hair stage 3</td>
<td>0.200 ± 0.417</td>
</tr>
<tr>
<td>Maturation – Pubic hair stage 4</td>
<td>1.152 ± 0.395</td>
</tr>
<tr>
<td>Maturation – Pubic hair stage 5</td>
<td>1.511 ± 0.424</td>
</tr>
</tbody>
</table>

The variance of the random variable (constant)

<table>
<thead>
<tr>
<th>Level 1 (within individuals)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>1.077 ± 0.193</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level 2 (between individuals)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>2.227 ± 0.407</td>
</tr>
</tbody>
</table>

-2 x log likelihood 731.886

Values are means ± SEE.
The results of the linear additive multilevel regression analysis for the mean power output (W) from the 30 s maximal cycle sprints for elite and non-elite female adolescent athletes showed that there was no significant difference between elite and non-elite groups for mean power output (W) (Table 8.13). However, there was an effect of age and body mass showing that older, heavier females had higher mean power outputs (W) (P<0.05). There was an effect of maturation at PH stage 4 for all the participants showing that at this maturation stage mean power output (W) increases (P<0.05). There was a negative effect of skinfolds showing that as the sum of 4 skinfolds increased the mean power output for the female athletes decreased (P<0.05).

Table 8.13  Multilevel regression analysis of mean power output (watts) in elite and non-elite females.

<table>
<thead>
<tr>
<th>Fixed Explanatory Variables</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>323.970 ± 3.797</td>
</tr>
<tr>
<td>Sum of 4 skinfolds (mm) - gm</td>
<td>-1.061 ± 0.270</td>
</tr>
<tr>
<td>Age (Years) - gm</td>
<td>7.183 ± 2.524</td>
</tr>
<tr>
<td>Mass (kg) - gm</td>
<td>5.942 ± 0.513</td>
</tr>
<tr>
<td>Maturation – Pubic hair stage 4</td>
<td>10.297 ± 4.772</td>
</tr>
</tbody>
</table>

The variance of the random variable (constant)

<table>
<thead>
<tr>
<th>Level 1 (within individuals)</th>
<th>Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>554.612 ± 98.785</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level 2 (between individuals)</th>
<th>Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>954.365 ± 186.717</td>
</tr>
</tbody>
</table>

-2 x log likelihood                               1914.012

Values are means ± SEE.
The results of the linear additive multilevel regression analysis for mean power output (W.kg\(^{-1}\) FFM) from the 30 s maximal cycle sprints for elite and non-elite female adolescent athletes show that there were no differences in mean power outputs (W.kg\(^{-1}\) FFM) between the elite and the non-elite athletes, but there was an effect of maturation at PH stage 4 for all participants (Table 8.14). There was an effect of age showing that the older females had higher mean power outputs (W.kg\(^{-1}\) FFM) (P<0.05).

**Table 8.14**  Multilevel regression analysis of mean power output (watts.kg\(^{-1}\) FFM) in elite and non-elite females.

<table>
<thead>
<tr>
<th>Fixed Explanatory Variables</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>7.666 ± 0.220</td>
</tr>
<tr>
<td>Age (Years) - gm</td>
<td>0.165 ± 0.068</td>
</tr>
<tr>
<td>Maturation – Pubic hair stage 3</td>
<td>0.396 ± 0.230</td>
</tr>
<tr>
<td>Maturation – Pubic hair stage 4</td>
<td>0.710 ± 0.229</td>
</tr>
<tr>
<td>Maturation – Pubic hair stage 5</td>
<td>0.548 ± 0.262</td>
</tr>
</tbody>
</table>

**The variance of the random variable (constant)**

*Level 1 (within individuals)*

| Constant                                        | 0.327 ± 0.058   |

*Level 2 (between individuals)*

| Constant                                        | 0.585 ± 0.113   |

-2 x log likelihood                              | 489.844         |

Values are means ± SEE.
Chapter 8

Longitudinal Development

Table 8.15 shows the results of the strength measures on the Concept2 Dyno® for the elite and non-elite female adolescent athletes at each year studied.

Table 8.15  Strength measures in female elite and non-elite adolescent sports performers between 12 and 16 years (mean ± SEM)

<table>
<thead>
<tr>
<th>Age (yrs)</th>
<th>Elite</th>
<th>Non-Elite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n=86)</td>
<td>(n=100)</td>
</tr>
<tr>
<td>12.8 ± 0.1</td>
<td>(n=5)</td>
<td>(n=18)</td>
</tr>
<tr>
<td>13.5 ± 0.1</td>
<td>(n=25)</td>
<td>(n=27)</td>
</tr>
<tr>
<td>14.5 ± 0.0</td>
<td>(n=38)</td>
<td>(n=26)</td>
</tr>
<tr>
<td>15.5 ± 0.0</td>
<td>(n=44)</td>
<td>(n=36)</td>
</tr>
<tr>
<td>16.6 ± 0.1</td>
<td>(n=33)</td>
<td>(n=18)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Combined leg press (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite</td>
</tr>
<tr>
<td>n= 86</td>
</tr>
<tr>
<td>71 ± 6</td>
</tr>
<tr>
<td>(n=5)</td>
</tr>
<tr>
<td>95 ± 5</td>
</tr>
<tr>
<td>(n=24)</td>
</tr>
<tr>
<td>100 ± 3</td>
</tr>
<tr>
<td>(n=37)</td>
</tr>
<tr>
<td>105 ± 3</td>
</tr>
<tr>
<td>(n=40)</td>
</tr>
<tr>
<td>107 ± 5</td>
</tr>
<tr>
<td>(n=26)</td>
</tr>
<tr>
<td>Non-Elite</td>
</tr>
<tr>
<td>n= 100</td>
</tr>
<tr>
<td>83 ± 5</td>
</tr>
<tr>
<td>(n=18)</td>
</tr>
<tr>
<td>88 ± 3</td>
</tr>
<tr>
<td>(n=27)</td>
</tr>
<tr>
<td>98 ± 4</td>
</tr>
<tr>
<td>(n=25)</td>
</tr>
<tr>
<td>97 ± 3</td>
</tr>
<tr>
<td>(n=36)</td>
</tr>
<tr>
<td>93 ± 5</td>
</tr>
<tr>
<td>(n=18)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Arm press (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite</td>
</tr>
<tr>
<td>n= 86</td>
</tr>
<tr>
<td>28 ± 3</td>
</tr>
<tr>
<td>(n=5)</td>
</tr>
<tr>
<td>36 ± 2</td>
</tr>
<tr>
<td>(n=24)</td>
</tr>
<tr>
<td>39 ± 1</td>
</tr>
<tr>
<td>(n=36)</td>
</tr>
<tr>
<td>42 ± 1</td>
</tr>
<tr>
<td>(n=39)</td>
</tr>
<tr>
<td>41 ± 2</td>
</tr>
<tr>
<td>(n=26)</td>
</tr>
<tr>
<td>Non-Elite</td>
</tr>
<tr>
<td>n= 100</td>
</tr>
<tr>
<td>29 ± 2</td>
</tr>
<tr>
<td>(n=18)</td>
</tr>
<tr>
<td>32 ± 1</td>
</tr>
<tr>
<td>(n=27)</td>
</tr>
<tr>
<td>37 ± 1</td>
</tr>
<tr>
<td>(n=25)</td>
</tr>
<tr>
<td>36 ±</td>
</tr>
<tr>
<td>(n=36)</td>
</tr>
<tr>
<td>38 ± 2</td>
</tr>
<tr>
<td>(n=18)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Arm pull (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite</td>
</tr>
<tr>
<td>n= 86</td>
</tr>
<tr>
<td>27 ± 2</td>
</tr>
<tr>
<td>(n=5)</td>
</tr>
<tr>
<td>35 ± 2</td>
</tr>
<tr>
<td>(n=24)</td>
</tr>
<tr>
<td>36 ± 1</td>
</tr>
<tr>
<td>(n=36)</td>
</tr>
<tr>
<td>38 ± 1</td>
</tr>
<tr>
<td>(n=39)</td>
</tr>
<tr>
<td>39 ± 2</td>
</tr>
<tr>
<td>(n=26)</td>
</tr>
<tr>
<td>Non-Elite</td>
</tr>
<tr>
<td>n= 100</td>
</tr>
<tr>
<td>31 ± 2</td>
</tr>
<tr>
<td>(n=18)</td>
</tr>
<tr>
<td>33 ± 1</td>
</tr>
<tr>
<td>(n=27)</td>
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<tr>
<td>35 ± 2</td>
</tr>
<tr>
<td>(n=25)</td>
</tr>
<tr>
<td>35 ± 1</td>
</tr>
<tr>
<td>(n=36)</td>
</tr>
<tr>
<td>35 ± 2</td>
</tr>
<tr>
<td>(n=18)</td>
</tr>
</tbody>
</table>
There were no differences in the results of the linear additive multilevel regression analysis between the elite and non-elite female adolescent athletes for combined leg strength (Table 8.16). However, there was a main effect of mass showing that the heavier females were stronger in the combined leg push (P<0.05). There was a negative effect of sum of 4 skinfolds showing that as the sum of 4 skinfolds increased the amount that the females are able to push will decrease (P<0.05).

Table 8.16   Multilevel regression analysis of combined leg strength (kg) in elite and non elite females.

<table>
<thead>
<tr>
<th>Fixed Explanatory Variables</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>95.685 ± 1.319</td>
</tr>
<tr>
<td>Sum of 4 skinfolds (mm) - gm</td>
<td>-0.338 ± 0.111</td>
</tr>
<tr>
<td>Mass (kg) - gm</td>
<td>1.726 ± 0.197</td>
</tr>
</tbody>
</table>

The variance of the random variable (constant)

<table>
<thead>
<tr>
<th>Level 1 (within individuals)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>120.278 ± 18.785</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level 2 (between individuals)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>155.730 ± 31.767</td>
</tr>
</tbody>
</table>

-2 x log likelihood           1866.655

Values are means ± SEE.
The linear additive multilevel regression analysis for arm press strength (kg) for elite and non-elite female adolescent athletes showed that the elite athletes had a stronger arm press than the non-elite girls of ~2 kg (P<0.05) (Table 8.17). There was an effect of age and an effect of mass showing that the older, heavier females were able to press more weight with their arms (P<0.05). There was also an effect of circumference of the upper arm showing that females with larger upper arm circumferences were able to press more weight with their arms (P<0.05).

Table 8.17 Multilevel regression analysis of arm press strength (kg) in elite and non-elite females.

<table>
<thead>
<tr>
<th>Fixed Explanatory Variables</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>35.722 ± 0.618</td>
</tr>
<tr>
<td>Sum of 4 skinfolds (mm) - gm</td>
<td>-0.250 ± 0.044</td>
</tr>
<tr>
<td>Mass (kg) - gm</td>
<td>0.245 ± 0.096</td>
</tr>
<tr>
<td>Elite (Δ)</td>
<td>2.182 ± 0.927</td>
</tr>
<tr>
<td>Circumference of upper arm (mm) - gm</td>
<td>1.946 ± 0.338</td>
</tr>
<tr>
<td>Age (Years) - gm</td>
<td>0.846 ± 0.340</td>
</tr>
</tbody>
</table>

The variance of the random variable (constant)

<table>
<thead>
<tr>
<th>Level 1 (within individuals)</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>15.030 ± 2.312</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level 2 (between individuals)</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>14.352 ± 3.381</td>
</tr>
<tr>
<td>-2 x log likelihood</td>
<td>1372.469</td>
</tr>
</tbody>
</table>

Values are means ± SEE. Non elite females were used as a baseline with the elite females compared to it, indicated by (Δ).
Table 8.18 shows the results of the linear additive multilevel regression analysis for arm pull strength (kg) for elite and non-elite female adolescent athletes. The elite girls were able to pull ~2.5 kg more than the non-elite girls (P<0.05). There was an effect of mass showing that as the females got older they were able to pull more weight (P<0.05). There was also an effect of upper arm circumference showing that females with larger arm circumferences were able to pull heavier weight (P<0.05).

Table 8.18  Multilevel regression analysis of arm pull strength (kg) in elite and non-elite females.

<table>
<thead>
<tr>
<th>Fixed Explanatory Variables</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>34.022 ± 0.554</td>
</tr>
<tr>
<td>Mass (kg) - gm</td>
<td>0.368 ± 0.084</td>
</tr>
<tr>
<td>Circumference of upper arm (mm) - gm</td>
<td>0.654 ± 0.262</td>
</tr>
<tr>
<td>Elite (L1)</td>
<td>2.468 ± 0.837</td>
</tr>
</tbody>
</table>

The variance of the random variable (constant)

<table>
<thead>
<tr>
<th>Level 1 (within individuals)</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>5.724 ± 0.909</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level 2 (between individuals)</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>20.490 ± 3.009</td>
</tr>
<tr>
<td>-2 x log likelihood</td>
<td>1289.551</td>
</tr>
</tbody>
</table>

Values are means ± SEE. Non elite females were used as a baseline with the elite females compared to it, indicated by (L1).
8.3.2 Binomial Logistic Regression

Binomial Logistic Regression showed that for the elite female adolescent athletes $\dot{V}O_2$ peak (ml.kg$^{-1}$.min$^{-1}$), Maximum Heart Rate (beats.min$^{-1}$), Arm Push Strength (kg) and Blood Lactate Concentration (mmol.l$^{-1}$) at 9 km.h$^{-1}$ are key explanatory variables to distinguish them from the non-elite female adolescent athletes.
8.4 Discussion
The main results of the longitudinal study show, in brief, that the female elite adolescent athletes in this study had a higher peak VO$_2$ (ml.kg$^{-1}$.min$^{-1}$), a higher peak VO$_2$ (l.min$^{-1}$), and had lower maximum heart rate (beats.min$^{-1}$). There was an additive effect of maturation at breast development stage 4 for all the participants for peak VO$_2$ (ml.kg$^{-1}$.min$^{-1}$) and peak VO$_2$ (l.min$^{-1}$) showing that sexual maturation has an effect on the development of peak VO$_2$ (ml.kg$^{-1}$.min$^{-1}$) and peak VO$_2$ (l.min$^{-1}$). There was an additive effect of body mass and height for all the participants for peak VO$_2$ (l.min$^{-1}$), indicating that as the participants became taller and heavier their peak VO$_2$ (l.min$^{-1}$) increased. There was a negative effect of the sum of 4 skinfolds for all the participants for peak VO$_2$ (ml.kg$^{-1}$.min$^{-1}$), heart rate (beats.min$^{-1}$), and percentage of maximum heart rate, showing that as sum of skinfolds decreased there was an increase in peak VO$_2$ (ml.kg$^{-1}$.min$^{-1}$) and a decrease in heart rate (beats.min$^{-1}$), and percentage of maximum heart rate. Similarly, when performing a submaximal treadmill test, the elite female adolescent athletes had lower blood lactate concentrations (mmol.l$^{-1}$), lower heart rates (beats.min$^{-1}$) and ran at a lower percentage of their maximum heart rate than the non-elite female adolescent athletes during the period followed and there was a negative effect of maturation at breast development stage 4 for heart rate (beats.min$^{-1}$) showing that as maturity reached stage 4 heart rate (beats.min$^{-1}$) decreased. There was also an effect of sum of 4 skinfolds showing that as the sum of skinfolds increased so the heart rate (beats.min$^{-1}$) and the percentage of maximum heart rate increased. There was a negative effect of age for the elite girls showing that the percentage of their maximum heart rate that they ran at submaximally decreased as they got older. Blood lactate concentrations (mmol.l$^{-1}$) when running at 9.0 km.h$^{-1}$ increased with age in all girls.

Longitudinal analysis of peak VO$_2$ is mainly limited to boys and to untrained populations. The results of the present study suggest that sexual maturation in elite adolescent females increases peak VO$_2$ independently of other variables These results are supported by those of Geithner et al. (2004) who found in a study of 105 untrained male and female twin pairs that peak VO$_2$ (l.min$^{-1}$) increases throughout adolescence in both sexes but that females have lower values than males. Armstrong and Welsman (2001), conducted a longitudinal examination of peak oxygen uptake in relation to
growth in 11-17 year old untrained males and females (n=132) and likewise found that peak $\dot{V}O_2$ (l.min$^{-1}$) increased with age and maturity in both sexes. Fat-free mass was a dominant influence on the growth of peak $\dot{V}O_2$ (l.min$^{-1}$) in this particular cohort (Armstrong and Welsman, 2001). Sjödin and Svedenhag (1992) found, in elite males, that peak $\dot{V}O_2$ (ml.kg$^{-1}$.min$^{-1}$) remained stable in trained runners from ages 12 – 18 y but decreased in untrained males whose peak $\dot{V}O_2$ (ml.kg$^{-1}$.min$^{-1}$) decreased in the same period. In contrast, the non-elite girls in the present study continued to demonstrate an increase in Peak $\dot{V}O_2$ (ml.kg$^{-1}$.min$^{-1}$) and while this is likely to be an effect of maturation it may also be due to the fact that these non-elite girls were all active in sport at a school/local level.

One study that examined the longitudinal development of aerobic power in young athletes (swimmers, gymnasts, tennis players and footballers [males only]) was the TOYA study (Baxter-Jones et al., 1993). This study also found that $\dot{V}O_2$max in males and females increased with pubertal status, though when expressed in ml.kg$^{-1}$.min$^{-1}$ there was no observed increase in $\dot{V}O_2$max with maturation for the females, and indeed the female gymnasts had a greater $\dot{V}O_2$max (ml.kg$^{-1}$.min$^{-1}$) during the mid-pubertal stage than during the late pubertal stage. A multilevel regression modelling procedure was used to analyse the results which found that age, height and body mass were significant contributors to $\dot{V}O_2$max over time. However, the increase in aerobic power in the females toward the end of puberty was not significant, unlike that for the boys. Increases in aerobic power were particularly noticeable in the more aerobic sports such as swimming, which ties in with the results of our elite ‘individual endurance’ athletes (Chapter 5, Table 5.4) who had a significantly higher peak $\dot{V}O_2$ (ml.kg$^{-1}$.min$^{-1}$) than the ‘team players’, the ‘individual games players’ and the ‘individual other’ athletes. Similarly the multilevel regression analysis of the submaximal running results of the present study are underlined by the results of the study detailed in Chapter 5, where the elite athletes subset ‘individual endurance’ had lower heart rates, ran at lower percentages of their maximum heart rates and had lower blood lactate concentrations than the elite athletes subsets ‘team players’ or ‘individual others’. The longitudinal elite group had blood lactate concentrations of 1.5 mmol.l$^{-1}$ less than the non-elite group but the concentrations were shown to increase with age in both groups. Blood lactate
concentrations are known to be lower in children and adolescents at any given exercise intensity than in adults (Pfitzinger and Freedson, 1997a).

There is a paucity of literature examining longitudinal peak and mean power output in elite female adolescent athletes in comparison to their non-elite peers. In the present study there were no differences between the elite and non-elite athletes for either peak or mean power output whether analysed as an absolute measure (W). However, there were additive effects of age and body mass showing that as the girls got older and heavier both their peak and mean power output increased. There was a large additive effect of maturation at pubic hair stage 4 of showing an effect of sexual maturation on power output. There was a negative effect for the sum of 4 skinfolds for all the girls showing that as skinfold thickness decreased peak and mean power output (W) increased. Armstrong et al. (1997) reported an influence of maturation on peak and mean power output whether expressed in Watts, W.kg$^{-1}$ or with body mass controlled using allometric principles (100 boys and 100 girls) of 12 year olds. Later studies (Armstrong et al., 2001; De Ste Croix et al., 2001) found that maturation was not a factor in power output. This is in direct contrast to the findings on the current longitudinal study. It may be that the cohort in the present study is spread wider over the maturational range and therefore the current study is able to give a better feel for the underlying factors in the growth of peak and mean power. In the present study the main effect of maturation occurred at pubic hair stage 4 for peak power and mean power (W) and at pubic hair stage 5 for peak power (W.kg$^{-1}$) and pubic hair stage 4 for mean power (W.kg$^{-1}$). The later stages of maturation in female adolescents may have a hidden effect on power as it is an essential ingredient in the growth and changes in body mass, stature and body composition that occurs as the girls get older. The changes may be a causal effect of training as all the girls in our cohort were in some form of training. The elite girls in our group were leaner and had lower skinfold thicknesses, which is a negative term for the regression model for peak power output (W) and mean power output watts (W) showing that the lower the skinfold thickness the more power could be produced. When analysed by estimated fat free mass the effect of the skinfolds was removed.

Similarly there were no differences between the elite and non-elite athletes when peak and mean power output were ratio scaled by percentage of fat free mass (W.kg$^{-1}$ FFM).
When peak power output (W.kg\(^{-1}\) FFM) was analysed there was an effect of maturation at pubic hair stage 5 showing that sexual maturation had an effect on the peak power output from lean muscle mass. When mean power output (W.kg\(^{-1}\) FFM) was analysed there was an effect of age and an effect of maturation at pubic hair stage 4 showing that as the girls got older their peak power output from estimated lean muscle mass increased and when they reached pubic hair stage 4 of maturation there was an added increase in the mean power output from lean muscle mass.

There is a very little literature examining the muscle strength of adolescent girls either as a cross-sectional or as a longitudinal study. This study examined the muscle strength of the elite and non-elite girls over time. In boys, muscular strength has been shown to increase linearly with age from childhood until 13 or 14 years of age when there is a marked increase in strength through the pubertal stages which is followed by a slower increase until the boys reach their mid twenties (Armstrong and Welsman, 1997; Beunen and Malina, 1988). Girls have also been shown to experience an increase in muscular strength until they are about 15 years old, but show no evidence of an adolescent spurt (Armstrong and Welsman, 1997).

There were no differences between the elite and non-elite female adolescent athletes for combined leg press strength (kg). However, there was an effect of age showing that as the girls got older they got stronger and a negative effect of sum of 4 skinfolds showing that as the skinfold thickness reduced the girls got stronger reflecting the role of lean muscle mass in muscle strength.

When the arm pull and arm press strength measures were analysed the elite female adolescent athletes were stronger than the non-elite athletes. For the arm push strength measure there were also effects of age, body mass, and of arm circumference, showing that as the girls got older and heavier the girls were able to press more weight with their upper bodies. As the sum of skinfolds goes down they are able to press more weight, indicating that lean muscle mass may be a factor in upper body strength. The arm pull strength measure showed that, in addition to the elite girls being stronger than the non-elite girls there was an effect of body mass and of upper arm circumference for all the girls, indicating that as the girls got heavier and their upper arm circumference increased
that they were able to pull more weight. The maximal force that a muscle can generate is primarily due to the size of the muscle and the neural control of the generation of force (Malina et al., 2004b).

8.5 Conclusion

Thus it would appear that, as shown by the Binomial Logistic Regression, that for the elite female adolescent athletes $\dot{V}O_2$ peak (ml.kg$^{-1}$min$^{-1}$), Maximum Heart Rate (beats.min$^{-1}$), Arm Push Strength (kg) and Blood Lactate Concentration (mmol.l$^{-1}$) at 9 km.h$^{-1}$ are key explanatory variables to distinguish them from the non-elite female adolescent athletes. In addition, it seems that in female adolescent athletes that there are significant effects of maturation on performance particularly during the later stages of pubic hair and breast development. Body composition also seems to play a major role with the sum of 4 skinfolds being an indicator of leanness, indicating a greater proportion of active muscle mass.
CHAPTER 9

General Discussion

9.1 Key Findings

The key findings from this study were:

- The elite female adolescent athletes in this study were significantly more likely to have a later onset of menarche than the non-elite adolescent athletes (Chapter 4). The mothers of the elite female adolescent athletes were significantly more likely to have a later onset of menarche than the non-elite adolescent athletes.

- The elite female adolescent athletes were more likely to record a lower stage of maturational development as defined by Tanner's indices for pubic hair, in all age groups (Chapter 4). There was also a tendency for the elite girls to record a lower stage of maturational development as defined by Tanner's indices for breast development.

- The elite athletes had a larger thigh circumference when analysed by maturational stage, but not when analysed by age (Chapter 4). The elite girls also had a lower sum of circumferences, a smaller sum of 4 skinfolds and a lower estimated percentage of body fat when analysed by age group but not by maturation.

- The elite athletes had higher values for peak oxygen uptake (l.min⁻¹) and lower values for maximum heart rate (beats.min⁻¹) than the non-elite athletes for both maturation and age (Chapter 5). Once peak oxygen uptake was scaled by body mass (ml.kg⁻¹.min⁻¹) the elite athletes still had higher values than the non-elite athletes, but there was no longer an effect of age or maturation.

- Running economy was apparently poorer in the elite athletes when examined by age. However, when maturity was taken into account there were no differences in running economy between the two groups. Thus, the apparent poorer running economy of the elite girls when examined by age was because the elite girls were less mature at the same chronological age (Chapter 5). Blood lactate concentration during submaximal running was significantly lower in the elite
athletes but there was no effect of maturation or age. Heart rate, rate of perceived exertion, and R value were all lower in the elite athletes than the non-elite athletes during submaximal running by age and by maturation.

- Peak power output (W) during a 30 s maximal sprints was similar in elite and non-elite athletes but did increase with maturation and age (Chapter 6). When scaled by body mass (W.kg⁻¹) there were no effects of group, maturation or age. When mean power output (W) and (W.kg⁻¹) was analysed there was a main effect of group for both maturation status and for age. Blood lactate concentrations post sprint were similar for elite and non-elite athletes, but increased with age and maturity, although the elite athletes had significantly lower blood lactate concentrations after the warm-up protocol than the non-elite athletes.

- The elite athletes were stronger than the non-elite athletes when tested on the Concept2 Dyno® for arm press and pull when analysed by both age and maturity, but combined leg strength were similar in both groups (Chapter 6).

- The elite athletes made wider use of psychological skills in training and in competition than the non-elite athletes (Chapter 7). The elite athletes perceived a higher task and a higher ego orientation in significant others (coach, father, mother) in their sporting lives than did the non-elite athletes. The task and ego orientations of the elite athletes were similar to those of the non-elite athletes. The non-elite athletes were more intrinsically (i.e. just doing it for their own satisfaction) motivated to do their sport than the elite athletes.

- In elite and non-elite adolescent athletes followed longitudinally and analysed using multilevel regression modelling (Chapter 8), Binomial Logistic Regression showed that for the elite female adolescent athletes VO₂ peak (ml.kg⁻¹.min⁻¹), maximum heart rate (beats.min⁻¹), arm press strength (kg) and blood lactate concentration (mmol.l⁻¹) at 9 km.h⁻¹ are key explanatory variables distinguishing them from the non-elite female adolescent athletes. The elite athletes had a higher VO₂ peak (ml.kg⁻¹.min⁻¹) and a higher VO₂ peak (l.min⁻¹). The elite athletes also had lower heart rates (beats.min⁻¹), ran at lower percentages of their maximum heart rates and had lower blood lactate concentrations (mmol.l⁻¹) when performing submaximal treadmill running at 9 km.h⁻¹ than the non-elite female adolescent athletes. There was a negative effect
of skinfolds for $\dot{V}O_2$ peak (ml.kg$^{-1}$.min$^{-1}$) showing that as skinfold values increased $\dot{V}O_2$ peak decreased indicating that a greater fat free mass was beneficial to the female adolescent athletes. The results of the linear additive regression analysis for $\dot{V}O_2$ peak (ml.kg$^{-1}$.min$^{-1}$), and $\dot{V}O_2$ peak (l.min$^{-1}$) also showed that females at breast development stage 4 experienced an increase in $\dot{V}O_2$ peak indicating that there is an effect of maturation, independent of other variables on peak oxygen uptake during the later stages of puberty. There were no differences between the elite and non-elite females for peak or mean power output (W) or (W.kg$^{-1}$ FFM) these findings are consistent with those in the cross-sectional study in Chapter 6 except that in the cross-sectional data mean power was higher in the elite athletes. These slight differences in results between Chapter 6 and Chapter 9 may have been an effect of the different methods of statistical analysis and also due to the fact that the cross-sectional results are a snapshot of one moment in time, whereas the longitudinal study looks at the effects of aging and maturation on the athletes over a series of visits. There were positive effects of age, mass, and maturation at pubic hair stage 4/5 and negative effects of sum of skinfolds. The linear additive regression analysis for the strength measures on the Concept2 Dyno® showed no differences between the elite and non-elite female athletes for the combined leg press, but there was an effect of mass and a negative effect of sum of skinfolds. The results of the upper body strength measures showed that the elite female athletes were stronger than the non-elite athletes for both arm push and for arm press, supporting the results of the cross-sectional analysis in Chapter 6. For these two measures there were also additive effects of mass and the circumference of the upper arm. For the arm push there was also an additive effect of age and a negative effect of sum of 4 skinfolds.

- The elite athletes' were divided into 4 elite subsets, 'individual endurance', 'individual games players', 'individual others' and 'team games players' and the results from all the cross-sectional studies (Chapters 4, 5, & 6) were analysed with regard to these 4 subsets. The 'individual endurance' athletes were leaner than the 'team players' (Chapter 4). The 'individual other' athletes had an earlier onset of menarche than the 'individual endurance', 'individual games players' and the 'team games players'. The 'individual endurance'
athletes had smaller skinfold measures for the Supra-Spinale and Abdominal skinfold sites and smaller circumference measures for waist girth. The 'individual games players' had a smaller sum of all circumferences, than 'team games players', 'individual endurance' and 'individual others'. The 'team games players' had larger hip girths than the 'individual endurance', the 'individual games' and the 'individual others'. The 'team games players' had a larger sum of all circumferences than 'individual games players'. (Chapter 5)

The 'individual endurance' athletes had a higher \( VO_2 \) peak (ml.kg\(^{-1}\).min\(^{-1}\)) than the 'team games players', the 'individual others' and the 'individual games players'. The 'individual endurance' athletes had lower blood lactate concentrations when treadmill running at 3 speeds (8.0, 9.0, and 10 km.h\(^{-1}\)) than the 'team games players', the 'individual games players' and the 'individual other' athletes. The 'individual endurance' athletes had lower heart rates (beats.min\(^{-1}\)), ran at a lower percentage of their maximum heart rate and also had lower R values when treadmill running at 3 speeds (8.0, 9.0, and 10 km.h\(^{-1}\)) than the 'team players' and the 'individual other' athletes. The 'individual endurance' athletes reported lower rates of perceived exertion than the 'team players when treadmill running at 3 speeds (8.0, 9.0, and 10 km.h\(^{-1}\)). When the results for the 30 s maximal cycle sprint were analysed the 'individual endurance' athletes had lower peak power outputs (W) and lower mean power outputs (W) than the other elite subsets. When peak and mean power output were ratio scaled by estimated lean body mass (W.kg\(^{-1}\) LBM) the 'individual endurance' athletes had lower peak and mean power outputs than the other elite subsets. There were no differences between the elite athlete subsets for blood lactate responses to 30 s maximal cycle sprinting for the post warm-up and the 2 min post sprint time points. However, at 5 min post sprint the 'individual endurance' athletes had a lower blood lactate concentration than the other elite subsets. There were no differences between the elite subsets for any of the strength measures but the 'individual endurance' athletes consistently had lower values for all the tests than any of the other elite subsets.

To summarise, in this study it was found that the elite female adolescent athletes were late maturers and had a later onset of menarche that was, in all probability, genetically
determined. They were thinner, had less adipose tissue and more muscle in their thighs, although there were no differences in stature and body mass between the groups. The elite athletes had higher absolute peak oxygen uptakes (l.min⁻¹) and lower maximum heart rates (beats.min⁻¹) when analysed by age and maturation status. When ratio scaled by body-mass, peak oxygen uptake (ml.kg⁻¹.min⁻¹) was still higher for the elite athletes but there was no effect of age or maturation. The elite athletes were less economical than the non-elite athletes when performing submaximal running yet had lower blood lactate concentrations, lower heart rate (beats.min⁻¹), worked at a lower percentage of their maximum heart rates, reported lower rates of perceived exertion and had lower R values. During 30 s maximal cycle sprint older, more mature girls were stronger and able to produce a greater absolute (W) peak power. When these results were scaled to body mass this effect disappeared. The elite girls were able to produce a higher mean power output for both absolute (W) and ratio-scaled (W.kg⁻¹) whether analysed by age or maturation status. The elite athletes had higher blood lactate concentrations at post warm-up for the 30 s maximal cycle sprint. Blood lactate concentrations increased as the elite and non-elite athletes got older and more mature. The elite athletes were more skilled at using psychological strategies to assist them in their sporting performance than the non-elite girls and perceived that the significant people around them were both task and ego oriented with regards to their sporting success.

9.2 Elite and Non-Elite Adolescent Growth and Maturation

There has been only one published study in the United Kingdom that has investigated the physiological responses of elite adolescent athletes, to this author's knowledge. The Training of Young Athletes (TOYA) study (Baxter-Jones et al., 1993; Maffulli et al., 1994b; Baxter-Jones et al., 1994; Baxter-Jones et al., 1995; Baxter-Jones and Helms, 1996; Erlandson et al., 2008) was a longitudinal study that followed a large (n=453) cohort of young, British, male (n=231) and female (n=222) athletes [these 'n' were at the start of the study]. The athletes were drawn from four sports; gymnastics, soccer, swimming, and tennis. The study concentrated on four main areas of interest; sports injury, growth and development, psychological and psychosocial problems, and physiological functioning.
The current thesis is novel in that it has drawn adolescent female athletes from a wide range of sports, including fencing, tae-kwondo, rugby, football, volleyball, basketball, hockey, lacrosse, rowing, badminton, tennis, biathlon, triathlon, distance running, athletics (track), athletics (field), swimming, karate, water-polo, windsurfing, cricket, squash, netball, golf, and gymnastics. These girls were identified as elite either by their inclusion in their sport's governing body summer camps, chosen to attend because they were the best performers in their particular sport for their age, or by their performance at National level competition, or were identified as elite by their schools, (all the schools who participated in this study were specialist sports colleges and academies and gave this research access to their identified elite performers). This thesis is also novel as it includes a large group of non-elite athletes to act as controls. This enabled the research to identify the physiological and psychological characteristics, and to enable any changes over time to be identified, thus enabling the identification of those characteristics which might contribute to the elite status of the elite female adolescent athletes in this research. A further novel feature of this thesis was the identification and examination of the elite cohort divided into 4 elite subsets, ‘individual endurance’, individual games players’, individual others’ and ‘team games players’.

In Chapter 4 the physical growth of the elite and non-elite adolescents who participated in the research described throughout this thesis (Chapters 4, 5, 6, 7, and 8) was examined. There were no significant differences between the groups in terms of stature or body mass when compared either by age or sexual maturity, although the elite girls were consistently heavier than the non-elite girls at all stages of maturation and were consistently taller at all stages except stage 5. In the current study the participants' (both elite and non-elite) average percentiles were above the 50th percentile, for stature and body mass, of the UK90 reference curves at all ages (Freeman et al., 1995; Cole et al., 1995; Cole et al., 1998). This may have been due to selection bias, particularly within the non-elite group, with more athletic individuals volunteering to participate, or it may be that the widely reported trend towards earlier maturity and greater adult size has led to the current growth reference standards for Britain to become outdated.

Sexual maturity when determined by stage of genital development was less advanced in the elite females than in the non-elite females, with the elite females indicating
significantly less advanced pubic hair development and a tendency towards less pronounced breast development than the non-elite girls. These findings tie in nicely with the significantly later onset of menarche in the elite girls and in their mothers. Female elite athletes have been observed to demonstrate characteristics of ‘late maturers’ by several researchers (Malina, 1983; Baxter-Jones and Helms, 1996; Beunen and Malina, 1996), although other researchers have not been able to confirm this, with a large study examining the maturation status of international junior rowers finding no direct evidence to support the theory that ‘intensive........training has a negative influence on the maturation status of junior female athletes’ (Claessens et al., 2003).

The elite girls were less fat, had a smaller sum of circumferences and larger thigh circumferences than the non-elite girls. Overall, the picture of the elite female adolescent athlete that emerges is of a girl with a lean muscular physique, of slightly above average height and body mass, who is a late maturer, which may or may not be as a result of training. It is important to remember that sport selection factors such as physique and skill are also important selectors for sport and it may be that these ‘pre-select’ those who are going to be late maturers regardless of whether or not they participate in sport (Malina, 1983).

These differences in biological maturity between the female elite and non-elite adolescent athlete reinforces the argument that when sports related physiological function is examined it should be done so in relation to maturation status as well as chronological age.

9.3 Elite and Non-Elite Determinants of Performance

Chapter 5 compared the peak oxygen uptake (VO₂ peak) of elite female adolescent athletes with their non-elite counterparts. Many of the sports that our cohort competed in require endurance performance as a factor for success. The physiological determinants of endurance capability in many of the sports that our cohort take part in are thought to include peak VO₂, running economy and blood lactate concentrations during submaximal exercise.
\( \dot{V}O_2 \) peak (l.min\(^{-1}\)) and \( \dot{V}O_2 \) peak (ml.kg\(^{-1}\).min\(^{-1}\)) were higher in the elite groups whether expressed by age or maturity. This is consistent with earlier research which has found that both absolute and relative \( \dot{V}O_2 \) peak was higher in trained populations (Kobayashi et al., 1978; Sundberg and Eloainio, 1982; Van Huss et al., 1988; Eisenmann et al., 2001). The TOYA study also examined the relationship of peak \( \dot{V}O_2 \) to chronological age at different stages of maturity in young athletes in an attempt to separate the effects of training from those of growth (Baxter-Jones et al., 1993) and found that when age, height and body mass were controlled for using multi-level modelling, that \( \dot{V}O_2 \) peak increased with maturational status in both the male gymnasts, swimmers, football players and tennis players and the female swimmers, gymnasts and tennis players. Baxter-Jones et al. (1993) used the reference values from a study by Armstrong et al. (1991) as a comparison to an untrained cohort. However, the two studies were not similar as the Armstrong study used a discontinuous protocol for the treadmill running, whilst the Baxter-Jones study used a continuous protocol. Furthermore the methods for assessing maturity were totally dissimilar, with Armstrong et al., (1991) computing sexual maturation by means of an average of pubic hair rating with genitalia in boys and breast rating in girls, whilst Baxter-Jones et al (1993) used assessment to determine sexual maturity. In the current study the elite female adolescent athletes had higher \( \dot{V}O_2 \) peak values than the non-elite female adolescent athletes even when at the same maturation status and at the same age, suggesting that in addition to the delayed maturation there are other factors that are influencing the \( \dot{V}O_2 \) peak in elite female adolescent athletes. This may due to adaptations of training or to genetic factors.

This thesis is original in its study of running economy (Chapter 5) as it is only the second study to examine running economy with reference to chronological age and maturation status in elite female adolescent athletes who were drawn from a wide range of sports. There are only 4 published studies to this author’s knowledge, that have examined running economy in adolescent boys and girls (Cunningham, 1990b; Cunningham, 1990a; Fernhall et al., 1996; Ariëns et al., 1997) and of these only one looked at elite adolescent females (Cunningham, 1990b). Studies that have
examined running economy in elite/trained and untrained groups are even sparser with only two of these including female participants (Mayers and Gutin, 1979; Van Huss et al., 1988; Sjödin and Svedenhag, 1992). Van Huss et al (1988) found that in a study of trained male and female runners that running economy was superior in the comparison group of untrained runners aged 9–15 years. In the current study the non-elite female adolescent athletes were found to be more economical than the elite athletes when analysed by age, but there was no effect of maturity. Morgan et al (1995) found that elite (male) runners displayed better economy when compared to non-elite (male) peers. Only 9 of the elite cohort of the current study were distance runners which may, in part, explain why the elite girls were not more economical than their non-elite colleagues.

In addition, the initial treadmill speed of 8.km.h\(^{-1}\) may well have been too slow for the elite runners and thus could have affected their gait and rhythm.

Blood lactate concentrations during submaximal treadmill running were lower in the elite female adolescent athletes than they were in the non-elite female adolescent athletes (Chapter 5). This confirms the findings of Van Huss et al (1988) who found that the exercise (blood lactate was measured during a 3 minute recovery period between each stage of running) and recovery blood lactate concentrations of the elite female runners were consistently lower than those of the non-elite females. It was suggested that the non-elite male and female adolescents were consistently working at a higher relative exercise intensity (% \(\dot{\text{VO}}_2\) peak), leading to a greater contribution from their anaerobic energy systems and consequently higher blood lactate concentration (Van Huss et al., 1988). The other components of submaximal performance, heart rate, rate of perceived exertion and RER were all lower in the elite female adolescent athletes in this study and the divergence between running economy and these other variables warrants further investigation.

9.4 Elite and Non-Elite Power and Strength

In Chapter 6, Peak Power Output from 30 s maximal cycle sprints and strength measures were examined. No differences in PPO (W) or PPO (W.kg\(^{-1}\)) were found
between elite and non-elite female adolescent athletes, though there were effects of maturation and age for PPO (W), but only of maturation for PPO (W.kg\(^{-1}\)). Mean Power Output (W and W.kg\(^{-1}\)) during a 30 s maximal cycle sprints was higher in the elite female adolescent athletes with a main effect of maturation and a main effect of age for both. These results were supported by the results of the fatigue index which showed that the elite athletes fatigued significantly less quickly than the non-elite athletes. The findings of the current study are in direct contrast to Armstrong et al. (2001) and De Ste Croix et al. (2001) neither of whom found that maturation was a factor for peak or mean power output in the studies that they conducted.

Mean power output has been reported to reflect the muscular endurance capacity of the large muscles of the thigh (Van Praagh and Doré, 2002). The elite female adolescent athletes in the current study had a significantly larger thigh girths, and were less fat than the non-elite female adolescent athletes indicating a greater lean muscle mass in the thighs of the elite athletes, supporting the ability of the elite female athletes to produce a higher mean power output. It is possible that the higher mean power outputs of the elite female adolescent athletes were a result of training as well as a result of increases caused by growth and maturation. Doré et al (2001) examined the relationships between body dimensions and short term power output in three groups of non-athletic young females. A cohort of prepubescent (n=64), adolescent (n=62), and young adult (n=63) females all performed three all-out sprints on a friction loaded cycle ergometer. During growth peak cycling power increased, with significant differences between the young girls, the adolescents and the young women. The relationships between peak power output and the body mass of each of the groups were all significant. In the prepubescent and adolescent girls peak power was better related to lean leg volume and fat free mass than to body mass. The female adults exhibited a greater peak power output than both the other groups even when related to lean leg volume and fat-free mass showing that whatever the scaling variable was used, peak power output is greater in adult females than in prepubescent or adolescent girls (Doré et al., 2001). Whilst the above study only looked at peak power output it confirmed the effect of growth and maturation on peak power output that was found in the current study.
Power is the product of force and velocity, therefore it might be expected that the characteristics of skeletal muscle that relate to the production of force and velocity are those that determine peak power. The force that a muscle generates is related to the cross-sectional area of the active muscle, and the velocity of the muscular contraction relates to the length of the muscle fibre (Martin and Malina, 1998). Martin et al. (2003) found, in a study to examine the changes with age in cycling peak power (W) in a cohort of 132 young males aged between 9.5 – 16.5 years, [prepubertal (n=37), pubertal (n=47) and post-pubertal (n=48)] with the same lean leg volume (LLV), leg length (LL) and percentage body fat, that there were no significant differences for LLV, LL or percentage body fat. Peak power (W) increased significantly with age, demonstrating that when anthropometric characteristics were controlled peak power still increased with age in young boys (Martin et al., 2003). Peak power and mean power in boys closely corresponded to estimated thigh muscle mass in boys, which suggests that one of the major determinants of the variation in age related changes in peak power is the development of muscle mass (Martin and Malina, 1998). There is a paucity of published research examining these variables in elite or non-elite female adolescent athletes, but the results of the present cross-sectional study in this thesis were partially confirmed by those of the longitudinal study which showed that age, body mass and maturation had additive effects on both peak and mean power output for elite and non-elite female adolescent athletes.

Blood lactate concentrations (mmol.l\(^{-1}\)) during the 30 s maximal cycle sprint protocol only showed differences between the elite and the non-elite athletes during the post warm-up stage whether analysed by age or maturation status. However, blood lactate concentrations post-sprint increased with age and maturity. These higher post exercise blood lactate concentrations in older more mature girls may reflect increased activities of glycolytic enzymes (Ekblom, 1969; Eriksson et al., 1971). Other studies have failed to find an effect of maturation on blood lactate concentrations following intense exercise (Armstrong et al., 1997), so the present study is the first to show an effect of maturation on post sprint blood lactate concentrations.
A novel aspect of the current study was the examination of the strength of the elite and non-elite female adolescent athletes (Chapter 6). The elite female adolescent athletes had greater upper body strength than the non-elite athletes when analysed by both age and maturation status which may reflect their training status. As strength is defined as the maximal force that is generated by muscle during a single voluntary effort (Blimkie and Bar-Or, 2008), it follows that as muscle size and mass increases so the amount of force that can be generated will increase. The elite female adolescent athletes in the current study were demonstrably stronger than the non-elite athletes when analysed by maturation status in all strength tests except for right leg push and arm pull. The larger lean muscle mass in the thighs of the elite girls may be an indication that this is an effect of training. There is a need for further research in this area with adolescent females.

9.5 Psychological Characteristics of Elite and Non-Elite Performers

Chapter 7 examined the psychological profile and psychological skills usage of the elite and non-elite female adolescent athlete. The elite athletes in the current study were found to make use of psychological skills in practice and in competition. Young athletes are able to make choices about behaviour that will affect their levels of achievement in sport. They can choose whether or not to invest in psychological skills (training) and strategies. They can choose how hard they work at these skills and whether they use them and adhere to them. They can choose whether or not to persist when facing challenges to their personal perceptions of their ability (e.g. when they are not winning) (Harwood et al., 2004).

The elite athletes in the present study perceived that their coaches, parents and significant others around them, had higher task and higher ego orientations than did the non-elite girls of the significant others around them. The elite and non-elite female athletes had very similar scores when they were assessed for achievement goal orientation. Magyar and Feltz (2003) found that in adolescent girls (180 volleyball players aged 12 – 18 y) task orientation and perceptions of mastery climate were positively associated with adaptive sources of sport confidence and also with social and environmental sources. Ego orientation was positively associated with maladaptive
sources of confidence (Magyar and Feltz, 2003). Coaches can help to build self-confidence in their athletes by establishing a mastery climate in their training and for their athletes (Magyar and Feltz, 2003).

Another facet of achievement goal behaviour is the concept of self-handicapping. Self-handicapping is used by some people to protect themselves from negative feedback in socially evaluative environments such as competitive sport by reducing effort and creating excuses about their performance. Self-handicapping, whilst increasing the likelihood of failure, gives the individual the opportunity to protect their self-esteem and externalise their poor performance (Kuczka and Treasure, 2005). Kuczka and Treasure (2005) noted that self-handicapping is centred around perceived ability, and found that athletes who perceived an event to be of low personal importance reported more self-handicaps in the week prior to competition than those individuals who attached high importance to the tournament (Kuczka and Treasure, 2005). It would seem that if the sport context has a motivational climate that emphasises task-involvement and self-referenced comparisons of ability, then the possibility that an athlete will self-handicap and become demotivated will be reduced (Kuczka and Treasure, 2005).

Thus it is vital that young elite female (and male) athletes are equipped with the knowledge to enable them to use sports psychology to assist them in their sporting career, and that the significant others who surround them on a day to day basis, coaches, parents, peers and friends, help to create the motivational climate that give the young athlete confidence (Magyar and Feltz, 2003)

9.5 Longitudinal Development of Physiological Characteristics

Cross-sectional studies provide important information about the development of the physiological characteristics of young people, but longitudinal studies are enormously important as they give the researcher the opportunity to track developmental changes in exercise performance measures and to distinguish the effects of training from those of normal growth. There has been no research to date that has used a multilevel regression modelling approach to examine the age and maturity-related development of $\dot{V}O_2$ peak, heart-rate, percentage of maximal heart-rate, blood lactate concentrations when
submaximal running at 9 km·h\(^{-1}\); power output and strength measures in elite and non-elite female adolescent athletes.

When the results of Chapter 8 are examined it is clear that sexual maturation has an additive effect on the development of \(\dot{V}O_2\) peak (ml·kg\(^{-1}\)·min\(^{-1}\)) and \(\dot{V}O_2\) peak (l·min\(^{-1}\)) in all participants and that body mass and stature also have an additive effect on these two variables. However, there was a negative effect of the sum of 4 skinfolds for all participants for \(\dot{V}O_2\) peak (ml·kg\(^{-1}\)·min\(^{-1}\)) and heart rate (beats·min\(^{-1}\)) and percentage of maximum heart rate, showing that the leaner, more muscular athletes have higher peak oxygen uptakes, lower heart rates (beats·min\(^{-1}\)) and worked at lower percentages of maximum heart rate. Similarly when performing a submaximal treadmill test the elite athletes had lower blood lactate concentrations (mmol·l\(^{-1}\)), lower heart rates (beats·min\(^{-1}\)) and ran at a lower percentage of their maximum heart rate than the non-elite athletes. There was a negative effect of breast development at breast development stage 4 for heart rate (beats·min\(^{-1}\)) showing that as maturity reached stage 4 so heart rate (beats·min\(^{-1}\)) decreased. Sum of 4 skinfolds again had an effect, this time additive, showing that as the sum of 4 skinfolds increased so the heart rate (beats·min\(^{-1}\)) and the percentage of maximum heart when the participants were running at 9 km·h\(^{-1}\) increased. As the elite girls got older they ran at a lower percentage of their maximum heart rate when running submaximally. Blood lactate concentrations (mmol·l\(^{-1}\)) when running at 9 km·h\(^{-1}\) increased with age in all the girls.

Maturation was also found to play a significant role in the development of \(\dot{V}O_2\) peak; and in heart rate when running submaximally. There were no differences between the elite and non-elite for peak or mean power output (W) (W·kg\(^{-1}\)) but again maturity plays a large role. Sum of skinfolds was a factor in the linear additive regression analysis for many of the variables, indicating that leanness is desirable for an elite athlete. In the strength tests the circumference of the upper arm was important indicating that muscle size is a factor in strength. The elite female adolescent athletes when examined longitudinally were clearly demonstrating additional effects to those of age and maturity that affected all the participants as they matured and got older. The elite girls were leaner (as expressed by the sum of 4 skinfolds) than the non-elite athletes and the sum of 4 skinfolds, as an indicator of lean muscle mass, is an influential variable for several
of the results. Whether these were purely a result of training or whether genetics also play a part is an area for future study.

While multi-level modelling showed changes over time and the differences in development between elite and non-elite, it is interesting to know which factors, taken across all ages of subjects but controlling for maturation and age, were more important in distinguishing elite from non-elite. Binomial regression analysis revealed that the key explanatory variables to explain the differences between the elite and non-elite adolescent female athlete were, $\dot{V}O_2$ peak, maximum heart rate, blood lactate concentration when running at 9 km.h$^{-1}$ and arm push strength (Chapter 8). Genetic makeup and training status will be factors in the development of these key variables. Lower blood lactate concentrations will be affected by the $\dot{V}O_2$ peak of the athlete as well as by their training status, a fact supported by the age x group interaction for blood lactate concentration in the longitudinal analysis. The upper body strength of the elite athletes also indicates a possible training effect. These results have a relevance for talent identification, thus if individuals of the same maturity are compared, those with higher $\dot{V}O_2$ peak, maximum heart rate, blood lactate concentration when running at 9 km.h$^{-1}$ and arm push strength are most likely to be elite.

9.6 Summary

Thus, this thesis asserts that in studies of elite and non-elite female adolescent athletes that the elite female adolescent athlete may be a superior performer due to differences in $\dot{V}O_2$ peak, maximum heart rate, blood lactate concentration when running at 9 km.h$^{-1}$ and arm push strength as explained by the Binomial Regression analysis conducted during the longitudinal study. Furthermore, the elite female adolescent athlete may be a superior performer due to differences in maturation, that is later maturation in elite females and a later onset of menarche. A key determinant of success in endurance performance, and therefore in reaching elite status, appears to be a high $\dot{V}O_2$ peak. This is almost certainly a genetic characteristic. Elite female adolescent athletes have lower blood lactate concentrations in exercise, though it is not clear what the exact
mechanisms for this are. The elite female adolescent athlete appears to be able to run at a considerably lower intensity than her non-elite peers, but whether this is a factor of training or genetics has yet to be elucidated. Running economy is not the clear explanatory variable that it was thought to be to explain the differences between elite and non-elite female adolescent athletes, indeed in our breakdown of the elite athletes into subsets it was the 'individual games players' who had the best running economy and not the 'individual endurance' athletes as might have been expected. It would appear that power output is strongly influenced by maturation and age in adolescent females, though there also appears to be a training effect with the elite female adolescent athlete able to produce a high mean power, indicating muscle endurance capabilities. When we examined strength it would appear that the elite female adolescent athlete is stronger than the non-elite female athlete. Maturity and age appear to play a part in strength but it is highly likely that there is a training effect being manifested here as well. Lastly, it would seem that the elite female adolescent athletes in this study are using psychological skills to assist them in their sporting success. Whether the goal disposition of the elite female adolescent athlete is able to be amended by coaches/parents/the athlete themselves, in order to better achieve at a high level remains to be seen.

- Small 'n' for the longitudinal study. As the number of returners was comparatively small the results may have been influenced to a greater extent than was desirable by the cross-sectional data that was included in the multi-level modelling.
- Elite Athlete Subsets were not included in Binomial Regression analysis and Psychological analysis as the 'n' for each of the subsets was small and it was felt that meaningful results would have been difficult to obtain.

9.8 Directions for future research

- Investigation of the current (National/International) mean age of menarche in athletes and non-athletes, by race and socio economic variables would be very valuable. The most recent research of the mean age of menarche in Britain was by Whincup et al (2001) with a relatively small 'n' of 1166 girls born between
1982 and 1986. There is a commonly held view that the mean age of menarche is lowering but this needs to be investigated so that when an elite group of athletes is examined their data can be compared with national norms for their age, race and socio-economic status and with other athletic groups.

- Investigation of the correlation between parental sporting background and the performance of their children, mothers' age of menarche and relationship between the mother and child's sporting attainment levels and age of menarche. There is evidence (Kay, 2000; Kay, 2004) that children of 'sporty' parents are more likely to become 'sporty' themselves. There is also evidence that the age a girl attains menarche is closely linked to the age that her mother attained menarche (Baxter-Jones et al., 1994). If a late maturing 'sporty' mother has daughters are they more likely to have the necessary physiological and psychological characteristics that pre-dispose them to achieving at a high level in sport?
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References


APPENDICES

A. Letter to Parents
B. Participant Information Pack and Consent Forms
C. Parental Questionnaire
D. Health History Questionnaire
E. Tanner Scales - Female
F. Family Background Questionnaire
G. Test of Performance Strategies
H. Individual Sport Motivated Climate Scales
I. Beliefs About the Causes of Success Questionnaire
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L. Method for Lactate Assay (Maughan 1982)
DATE

Dear Mr and Mrs Xxxxxxxxxx

The Institute of Youth Sport (School of Sport and Exercise Sciences, Loughborough University) is conducting a longitudinal study investigating the physiological and psychological development of young female sports performers, and we are looking to recruit individuals aged between 12 and 15 years of age, who have been classed as gifted and talented in sport, to take part in the study. Participation will require performers to visit the laboratory at Loughborough University for a day once every 4 - 6 months for the next 18 - 24 months (also, please see the enclosed information pack for a description of the tests undertaken). Your daughter xxxxxxx has been identified as someone who might be interested in this study and we would like to invite xxxxxxxxx to consider becoming a participant. If, following discussion with you she would like to become involved, please (contact Persephone Wynn using either the telephone number or e-mail provided below / complete the school consent forms attached).

The Loughborough University staff supervising the study, ensure that the exercise testing undertaken by participants is safe, enjoyable and educational. All participants in the study are collected and returned (either to school or home) by car. They are also given lunch on campus. The guidelines followed by staff meet the rigorous ethical standards set out by Loughborough University, and all staff are Criminal Records Bureau (CRB) approved.

All participants in the study will receive a regular breakdown of their results. As part of the educational experience, as well as taking part in the study, participants will have the opportunity to visit the university to tour its facilities in the summer term. If you have any questions about the study please contact Dr John Morris using either the telephone number or e-mail below.

Yours sincerely

XXXXXXXX XXX

Headteacher/Head of PE
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Physiological Laboratory Testing Information

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**Test Information for Young People and Parents**

**Laboratory Tests**
Performed in a laboratory at the university.

- Submaximal intensity running test (light to hard running but below maximum)
- Uphill running test (running uphill for as long as you can)
- Strength tests
- Sprint bike test

**Other Measurements**
Performed in a laboratory at the university.

- Height and weight
- Lung volume and peak flow of lungs - to measure how much and how fast you can breathe out air
- Health, nutrition and physical activity questionnaires
- Self-assessment of maturity
- Skinfold and circumference measurements - to measure the amount of fat in the body
- Psychological and Socio-demographic questionnaires
You will be given the chance to practice running and stopping on the treadmill and bicycle before the tests start, until you feel confident. Also, you will put on a mouthpiece and nose clip to practice breathing normally. You will have plenty of time to rest between each test.

**Low Intensity or Sub-Maximal Running Test**

This first test involves running on a treadmill at different speeds. Sub-maximal means that the test will be stopped before you start to find it really difficult to keep running. To begin you will run at a slow and easy speed for 4 minutes, after which the treadmill speed is increased and you will run for a further 4 minutes. If you can manage it, the treadmill speed will be increased and you will run for a further 4 minutes. Most young people will complete 2-3 levels of increased speeds, i.e. 8-12 minutes of running, but if you are a very good runner you may complete 4 or 5 levels.

During the last minute of each level you will put the mouthpiece in while running and we will collect the air you breathe out. Then while you are still running you will place your hand on the rail of the treadmill and we will take a small finger prick blood sample. The minimum number of blood samples taken is two, and the maximum is 6 depending on how long you run for.

**Uphill Treadmill Running Test**

This test measures the maximum amount of oxygen (the substance in air we require to be able to breath) you can take into your body and use in your muscles to produce energy (peak oxygen uptake). To begin with the treadmill speed is slow and the gradient is gentle. Every few minutes you will put the mouthpiece in and the air you breathe out is collected. The treadmill gradient is then increased but the speed remains constant. When you feel you are only able to keep running for one more minute, you indicate this to the tester by raising one finger clearly in the air. An air sample is then collected during this minute. If you need to stop before the end of the minute just take hold of the treadmill railing and remove your feet as practised.
**Strength Test**

This is a test of how strong the muscles in your upper body (arms, chest and back) and lower body (legs and bottom) are. This test is performed seated on a machine specially designed to measure strength. You will perform three warm-up repetitions of an arm push (arms bent at chest height and then pushed out from the chest until the arms are straight) and arm pull (arms straight out in front at chest height and pulled into the chest) movement on the machine followed by three maximal efforts to determine your upper body strength. You will then perform three warm up repetitions on left, right and combined leg push (seated leg/s bent then straightened) followed by three maximal efforts to determine your leg strength.

**Sprint Bike Test**

This test is a 30-second sprint on a stationary bicycle. After a warm up you will be asked to maintain a steady pedaling speed. With the command 3-2-1-GO! weights will be added to the bicycle and you will be asked to sprint as fast as possible for 30-seconds. A small finger-prick blood sample will be taken before the sprint and two samples after the sprint.
Skinfold and circumference measurements

These measurements are made to estimate the proportion of fat, and the dimensions of different parts of your body. The measurements will be made at 7 different places on your body: the front of the upper arm (biceps), the back of the upper arm (triceps), the base of your shoulder blade (sub-scapular), near your belly button (abdomen), and at the thigh and the calf. All the measurements will be made on the left hand side of your body.

To make the skinfold measurements a mark with a washable felt pen will be made on your skin at the sites listed above. A fold of skin is then held gently by the researcher and a piece of equipment (a 'skinfold caliper') is used to measure the size of the fold. This will be done at all sites and repeated to ensure the measurements are correct. The circumferences of your limbs and body will be measured using a special tape at the same places and the measurements also taken more than once.

Self-Assessment of Maturity

The reason for this assessment is that young people of the same age can be at very different stages of maturity, e.g. 13-14 year old boys may look slim and slight or tall and thicker-set depending on whether or not they have gone through puberty. It is a better comparison to examine the performance results of young people of the same maturity rather than of the same age. The assessment procedure requires you to enter an enclosed room on your own and carefully study some pictures of different stages of development (e.g. breast development and amount of pubic hair). You should then hold-up or pull-down your clothing (there is no need to completely remove clothing) and look in the mirror and decide which picture most closely matches your own stage of development. Write the number of that picture down on the form, place the form in the envelope and seal it. Fully replace all of your clothing before leaving the room and hand the envelope to the person leading the testing.
Lung volume and peak flow of lungs - to measure how much and how fast you can breathe out air

These measurements are made to estimate the size of your lungs and the speed and amount of air you can breathe out in one breath. The measurement of your lung volume is made with you standing up. You place a nose clip on your nose, take a big breath of air and then blow out one long breath through your mouth into a tube until your lungs are empty. The action of breathing out activates a pen which records the volume of air in your lungs for that blow on a piece of graph paper which is attached to the measuring machine.

To measure the peak flow of air from your lungs you will stand up and breath out through your mouth as hard as you can into a small measuring device, called a peak flow meter. This gives us a measurement of how many litres of air per breath you can blow out.

Possible risks and discomfort:
Two of these tests involve maximal exercise and are therefore demanding. However, you will have practised the procedures involved. The finger-prick blood samples maybe uncomfortable and may cause your finger to feel a little sore for a couple of days. This type of blood sampling is very common in sport science testing.

You will be provided with a full set of your own results, but these will be posted to you because of the time taken to analyse the blood samples.
**Young Person's Willingness to Participate Form**

Please read the statements below and indicate whether you are willing to participate in this study.

**Willingness to Participate Statement:**

- I have read the information about the tests and the tests have also been explained to me. I have had the opportunity to ask questions and I understand what is required of me. I know that I can say that I do not wish to continue with the testing at any time and I do not have to give a reason.

- I agree to take part in the tests listed below (please tick):

**Tests**

- Speed lactate treadmill running
- Peak Oxygen uptake test
- Finger prick blood samples
- Strength Test
- Sprint Bike Test
- Height and weight
- Health, nutrition and physical activity questionnaires and diaries
- Self-assessment of maturity
- Psychological and Socio-demographic questionnaires
- Lung volume and peak flow of lungs
- Skinfold and circumference measurements

Signed: ___________________________  Date: ___________________________

Witnessed by: ___________________________
Parent/Guardian Consent

- I have been invited to observe procedures.

- I have been given the opportunity to ask questions (please contact Dr John Morris if you have any questions, see below) and I understand what is required from my daughter.

I have seen the information sheet and fully understand what the tests entail:

Tests
* Speed lactate treadmill running * Peak Oxygen uptake test * Finger prick blood samples * Strength Test * Sprint Bike Test * Height and weight * Health, nutrition and physical activity questionnaires and diaries * Self-assessment of maturity * Psychological and Socio-demographic questionnaires * Lung volume and peak flow of lungs * Skinfold and circumference measurements

- I give permission for my daughter (please print your daughter's name) to spend a day away from school during term time to be involved in the testing.

- I give permission for my daughter (please print your daughter's name) to be involved in the testing.

- Parent/guardian's signature

- Parent/guardian's name (please print)

- Does your daughter take any medication? Yes □ No □
  If yes, please explain:

- Does your daughter have a medical condition? Yes □ No □
  If yes, please explain:

Direct line for Dr John Morris: 01509 226314
Email address for Dr John Morris: J.G.Morris@lboro.ac.uk
Mother's Menarchal Age

There is believed to be a strong association between the age that a girl's mother attained menarche (date of first period) and the age that her daughter(s) attain menarche. In order to test this belief it would be greatly appreciated if the mothers of the participants in this study could supply us with the following information:

Daughter's Name:...........................................................................................................................

Daughter's Date of Birth...........................................................................................................

Age of mother when first menstrual period occurred? (as near as you can remember please)...........................................................................................................................

Thank you for your assistance with this part of the research.
We would be very grateful if parent/s or guardian/s would complete this questionnaire and answer as many of the questions as you feel able.

Child’s Name ________________________________

1. What is your relationship to the above named child? ________________________________

2. What is your religion?  
   This question is voluntary

   None
   Buddhist
   Hindu
   Sikh
   Muslim
   Christian (including Church of England, Catholic, Protestant and all other Christian denominations)
   Jewish
   Any Other Religion

3. What is your country of birth? ________________

4. What is your ethnic origin?  
   (Ethnic origin questions are not about nationality, place of birth or citizenship. They are about colour and broad ethnic group – UK citizens can belong to any of the groups indicated).

   White
   British
   Irish
   Any other White background (please specify).................................

   Mixed
   White & Black Caribbean
   White & Black-African
   White & Asian
   Any other Mixed background (please specify).................................

   Asian or Asian British
   Indian
   Pakistani
   Bangladeshi
   Any other Asian background (please specify).................................

   Black or Black British
   Caribbean
   African
   Any other Black background

   Chinese or other ethnic group
   Chinese
   Any other (please specify).................................

5. What is the approximate income of your household in a year?
6. Which of these qualifications do you have?

Please tick all the qualifications that apply or, if not specified, the nearest equivalent.

- 1+ O levels/CSEs/GCSEs (any grades) [ ] NVQ Level 1 foundation GNVQ [ ]
- 5+ O levels, 5+ CSEs (grade 1), 5+ GCSEs (grades A-C), School Certificate [ ] NVQ Level 2, Intermediate GNVQ [ ]
- 1+ A levels/AS levels [ ] NVQ Level 3, Advanced GNVQ [ ]
- 2+ A levels, 4+ AS levels [ ] NVQ Levels 4-5, HNC, HND [ ]
- Higher School Certificate [ ] First Degree (eg BA, BSc) [ ] Other Qualifications (eg City and Guilds, RSA/OCR, BTEC/Edexcel) [ ]
- Higher Degree (eg MA, PhD, PGCE, Post-graduate certificate diplomas) [ ] No Qualifications [ ]

7. Do you have any of the following professional qualifications?

Please tick all the boxes that apply.

- No Professional Qualifications [ ] Qualified Dentist [ ]
- Qualified Teacher Status (for schools) [ ] Qualified Nurse, Midwife, Health Visitor [ ]
- Qualified Medical Doctor [ ] Other Professional Qualifications [ ]

7. Are you any of the following?

Please tick all the boxes that apply.

- Retired [ ] Student [ ]
- Looking after home/family [ ] Permanently sick/disabled [ ]

8. Are you?

Please tick all the boxes that apply.

- In full time employment [ ] In part time employment [ ]

If you are employed what is the full title of your main job?

______________________________________________________________________________________________

How many hours a week do you usually work in your main job?

______________________________________________________________________________________________

How much on average do you earn each year?

______________________________________________________________________________________________
9. What type of accommodation does your household occupy?

- A whole house or bungalow that is:
  - Detached
  - Semi-detached
  - Terraced

- A flat, maisonette, or apartment that is:
  - In a purpose-built block of flats or tenement
  - Part of a converted or shared house (includes bed-sits)
  - In a commercial building (for example, in an office building, or hotel or over a shop)

- Mobile or temporary structure:
  - Caravan or other mobile or temporary structure

10. Does your household own or rent the accommodation?

- Owns outright
- Pay's part rent and part mortgage (shared ownership)
- Lives there rent free
- Owns with a mortgage or loan
- Rents

11. If you have a landlord who is your landlord?

- Council (Local Authority)
- Private landlord or letting agency
- Employer of a household member
- Relative or friend of a household member
- Housing Association
- Housing Co-operative
- Charitable Trust
- Registered Social Landlord
- Other

12. Do you smoke?

No per day.................................

Yes  No

13. Do you drink alcohol?

Amount per week..........................

Yes  No

14. Are you diabetic?

Yes  No  Don't know

15. Do you have high blood pressure?

Yes  No  Don't know

16. Do you have high cholesterol levels?

Yes  No  Don't know
17. Do you suffer from Coronary Heart Disease?  
Yes [ ]  No [ ]  Don't know [ ]  
If yes please give details below.

Thank you for your cooperation!
HEALTH SCREEN FOR STUDY VOLUNTEERS

It is important that volunteers participating in research studies are currently in good health and have had no significant medical problems in the past. This is to ensure (i) their own continuing well-being and (ii) to avoid the possibility of individual health issues confounding study outcomes.

Please complete this brief questionnaire to confirm fitness to participate:

1. **At present**, do you have any health problem for which you are:
   - (a) on medication, prescribed or otherwise
   - (b) attending your general practitioner
   - (c) on a hospital waiting list

2. **In the past two years**, have you had any illness which require you to:
   - (a) consult your GP
   - (b) attend a hospital outpatient department
   - (c) be admitted to hospital

3. **Have you ever** had any of the following:
   - (a) Convulsions/epilepsy
   - (b) Asthma
   - (c) Eczema
   - (d) Diabetes
   - (e) A blood disorder
   - (f) Head injury
   - (g) Digestive problems
   - (h) Heart problems
   - (i) Problems with bones or joints
   - (j) Disturbance of balance/coordination
   - (k) Numbness in hands or feet
   - (l) Disturbance of vision
   - (m) Ear / hearing problems
   - (n) Thyroid problems
   - (o) Kidney or liver problems
   - (p) Allergy to nuts

4. If **you did** smoke or drink would you indicate that on a questionnaire such as this?

Name or Number

Date

PLEASE TURN OVER
5. Has any, otherwise healthy, member of your family under the age of 35 died suddenly during or soon after exercise? Yes □ No □

If YES to any question, please describe briefly if you wish (eg to confirm problem was/is short-lived, insignificant or well controlled.)

6. What is your ethnic origin?
(Ethnic origin questions are not about nationality, place of birth or citizenship. They are about colour and broad ethnic group – UK citizens can belong to any of the groups indicated).

White
British □
Irish □
Any other White background □
(please specify)..............................

Mixed
White & Black Caribbean □
White & Black-African □
White & Asian □
Any other Mixed background □
(please specify)..............................

Asian or Asian British
Indian □
Pakistani □
Bangladeshi □
Any other Asian background
(please specify)..............................

Black or Black British
Caribbean □
African □
Any other Black background □

7. Do you smoke? Yes □ No □
No per day..............................

8. Do you drink alcohol? Yes □ No □
Amount per week..............................
(one unit = ½ pint beer; 1 measure spirits, 1 glass wine)

Additional questions for female participants
(a) Have your periods started yet? Yes □ No □
If yes please answer (b) to (e)

PLEASE TURN OVER
(b) at what age did your periods start (as accurately as you can remember)?
Age.........................years and.......................months
(c) are your periods normal/regular? ........................................Yes □ No □
(d) are you on "the pill"?..............................................Yes □ No □
If yes what type?..........................................................
(e) could you be pregnant?............................................Yes □ No □
(f) What was the date of the first day of your last period?........

Thank you for your cooperation!

Loughborough University
TANNER STAGES:
FEMALE BREAST DEVELOPMENT

The pictures on this page show different stages of development of the breasts. A girl passes through each of the five stages shown by these pictures. Please look at each of the pictures and read the sentences next to the picture. Then choose the picture closest to your stage of development and mark an A on the picture. Then choose the picture that is next closest to your stage of development and mark a B on the picture.

Stage 1
The nipple is raised a little in this stage. The rest of the breast is still flat.

Stage 2
This is the breast bud stage. In this stage the nipple is little more raised. The breast is a small mound. The areola (darker, coloured middle part) is larger.

Stage 3
The areola and the breast are both larger than in stage 2, but the areola does not stick above the breast.

Stage 4
The areola and the nipple make up a mound that sticks up above the shape of the breast. (Note: this stage may not happen at all for some girls. Some girls develop from stage 3 to stage 5 with no stage 4).

Stage 5
This is the mature adult stage. The breasts are fully developed. Only the nipple stands out in this stage. The areola has flattened into the general shape of the breast.

Once you have completed the form, fold it and put it in the envelope provided and seal the envelope.

Your results are completely private and will be treated in complete confidence. No one will know who has filled out the form, as your name will not be on it.
TANNER STAGES:
FEMALE PUBIC HAIR DEVELOPMENT

The pictures on this page show different stages of development of female pubic hair. A girl passes through each of the five stages shown by these pictures. Please look at each of the pictures and read the sentences next to the picture. Then choose the picture closest to your stage of development and mark an A on the picture. Then choose the picture that is next closest to your stage of development and mark a B on the picture.

Stage 1
(no picture)

Stage 1
There is no pubic hair at all.

Stage 2
There is a little soft hair. Most of the hair is along the slit or lips. This hair may be straight or a little curly.

Stage 3
The hair is darker in this stage. It is coarser and more curled. It has spread out and thinly covers a larger area.

Stage 4
The hair is now as dark as that of an adult woman. However, the area it covers is not as large as that of an adult woman. The hair has not spread out to touch the thighs.

Stage 5
The hair is now like that of an adult woman. It also covers the same area as that of an adult woman. The hair usually forms a triangular (V) pattern as it spreads out to touch the thighs.

Once you have completed the form, fold it and put it in the envelope provided and seal the envelope. Your results are completely private and will be treated in complete confidence. No one will know who has filled out the form, as your name will not be on it.
Supporting Sports Talent: the role of your family

A. The first questions are just some general details about you, your family and your involvement in sport

A1. A) What is your name? 

B) Are you male or female?

A2. A) How old are you?

B) What is your ethnicity?

WHITE: 
British □ Irish □
White Other (Please specify) _______________________

BLACK OR BLACK BRITISH: 
Caribbean □ African □
Black Other (Please specify) _______________________

ASIAN OR ASIAN BRITISH: 
Indian □ Pakistani □
Bangladeshi □ Chinese □
Asian Other (Please specify) _______________________

MIXED PARENTAGE: 
White and Black Caribbean □
White and Black African □
White and Asian □
Mixed Other (Please specify) _______________________

OTHER ETHNIC BACKGROUND: (Please specify) _______________________

A3. A) Do you still live at home with your parents? 
If not, where are you now (e.g. college, university, in own home)?

B) How many brothers and sisters do you have?

A4. What is the main sport in which you participate?
A5. When did you first become involved in your sport (please tick)?
☐ Before the age of 4
☐ Age 5 - 8
☐ Age 9 - 12
☐ Age 13 and over

A6. What is the HIGHEST level at which you have competed? It is not necessary to fill in all the boxes on the chart: please just tick your HIGHEST level of performance.
☐ Club
☐ National
☐ Local (e.g. county) level
☐ International
☐ Regional
☐ Other (e.g. professional club signing)

A7. Are there any other family members who are, or have been, fairly serious competitors in sport? ('Serious' can mean anything from club level up to international standard!)
On the table below please indicate briefly whether either PARENT or any BROTHERS/SISTERS in your family have been quite seriously involved in sport, and if so, which sport, and what sort of level they have participated at.

<table>
<thead>
<tr>
<th>Which sport?</th>
<th>What level of competition/involvement? - e.g. club, regional, national, international; professional ... etc</th>
<th>Is this person still a regular participant in any sports?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mother</td>
<td></td>
<td>YES / NO</td>
</tr>
<tr>
<td>Father</td>
<td></td>
<td>YES / NO</td>
</tr>
<tr>
<td>Brother/sister</td>
<td></td>
<td>YES / NO</td>
</tr>
<tr>
<td>Brother/sister</td>
<td></td>
<td>YES / NO</td>
</tr>
<tr>
<td>Brother/sister</td>
<td></td>
<td>YES / NO</td>
</tr>
</tbody>
</table>

B. The next set of questions are about the support your family gives to enable you to perform in the sport

B1. Do your parents/guardians help in any of the following ways?
<table>
<thead>
<tr>
<th>PROVIDING TRANSPORT</th>
<th>Frequency: please give one answer for each item</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>usual number of days per week / weekend</td>
<td>please estimate frequency e.g. twice a year, monthly</td>
</tr>
<tr>
<td>To local training before school</td>
<td></td>
<td>NOT APPLICABLE</td>
</tr>
<tr>
<td>To local training after school</td>
<td></td>
<td>NOT APPLICABLE</td>
</tr>
<tr>
<td>To local training at weekends</td>
<td></td>
<td>NOT APPLICABLE</td>
</tr>
<tr>
<td>To training events and/or competitions outside the local area</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PROVIDING FINANCIAL SUPPORT</th>
<th>If possible, please estimate the ANNUAL cost. An approximate figure is fine. If you cannot do so, please leave the column blank.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paying for equipment and kit costs</td>
<td></td>
</tr>
<tr>
<td>Paying competition fees</td>
<td></td>
</tr>
<tr>
<td>Paying club membership fees</td>
<td></td>
</tr>
</tbody>
</table>

Are there any other expenses you would like to mention? If so, please describe, and if possible estimate their cost.

ADAPTING FAMILY ACTIVITIES: Would you say that any of the following are affected by the need to accommodate you and your sport?

<table>
<thead>
<tr>
<th></th>
<th>always</th>
<th>sometimes</th>
<th>rarely</th>
<th>never</th>
</tr>
</thead>
<tbody>
<tr>
<td>meal times</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>parents work hours</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>other children's activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>time family members spend with each other (e.g. each parent with the children)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>family weekends</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>family holidays</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If you would like to give an example of how any of the above are affected by your sport, please do so:

B2. Have you ever found it difficult to attend events/training because of: (please tick all answers that apply)

- [ ] The cost involved?
- [ ] The distance to travel?
- [ ] The time involved?
- [ ] Other commitments?
- [ ] any other factor (please explain)
B3. Have you ever been stopped from attending events/training because of:

- The cost involved?
- The time involved?
- The distance to travel?
- Other commitments?
- any other factor (please explain ______________________)

B4. Overall, how much impact would you say your participation in the sport has had on family life as a whole?

- No impact at all
- Very little impact
- A moderate impact
- A large impact
- It is/has been the main influence on family life

Please explain your answer:


B5. How would you describe the attitude of any brothers or sisters towards your involvement in the sport? (Please tick one answer)

- very positive
- quite positive
- neutral
- a bit negative
- very negative

B6. How do you feel about the time commitments that your parents/guardians have to give to your sport?


B7. Would you say that the amount of support families receive from the sport is:

- far too much
- a bit too much
- just right
- too little
- much too little
B8. Are there any ways in which you would like to see your family receive more support from the sport?

B9. In relation to your sport how helpful do you think the following could be to you and your family?

<table>
<thead>
<tr>
<th>Information on training</th>
<th>Very helpful</th>
<th>Quite helpful</th>
<th>Average</th>
<th>Not very helpful</th>
<th>Not at all helpful</th>
<th>Not sure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information in diet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Information on the impact on family life</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advice sheets/newsletters</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Information on websites</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Workshops to meet coaches and other experts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Opportunity to get together with other families involved in the sport</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Financial support</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

C. The final questions are just a few more details about your family situation.

C1. How many cars does your household own?

C2. Please give details of any parents'/guardians paid work:

<table>
<thead>
<tr>
<th></th>
<th>Does this person do paid work:</th>
<th>What type of job? Please give job title</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Full time</td>
<td>Part time</td>
</tr>
<tr>
<td>Mother/Female guardian</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Father/Male guardian</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Thank you very much for taking the time to complete this questionnaire.
Test of Performance Strategies - TOPS

Name: ______________________________________

ID Code: ______________________________________

This questionnaire measures performance strategies used by athletes in various sports situations. Because individual athletes are very different in their approach to their sport, we expect the responses to be different. We want to stress, therefore, that there are no right or wrong answers. All that is required is for you to be open and honest in your responses.

Throughout the questionnaire, several terms are used which may have different meanings for different individuals. Because of this, these terms are defined below with specific examples to sport where appropriate. Please keep these definitions in mind when responding to items with these terms.

**COMPETITION:** A tournament/meet where individuals or teams perform against each other.

**SKILL:** A specific element of your sport performance. For example, free throw shooting in basketball or a jump in figure skating.

**PERFORMANCE:** Your execution of specific sport skills during training and competition.

**ROUTINE:** A set of behaviours that is performed regularly in preparation for your performance in sport. An example may be going through specific stretches while listening to a song on your walkman prior to every performance.

**WORKOUT:** A structured practice session to work on various elements of your sport.

**VISUALISATION IMAGERY REHEARSAL:** These terms refer to the act of picturing in your mind some aspect of your performance. An example would be seeing and feeling yourself execute a specific skill perfectly.

© Developed by P.R. Thomas, S.M. Murphy, and L. Hardy (1996)
Each of the following items describes a specific situation that you may encounter in your training and competition. Please rate how frequently these situations apply to you on the following scale:

1 = Never  
2 = Rarely  
3 = Sometimes  
4 = Often  
5 = Always

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Never</th>
<th>Rarely</th>
<th>Sometimes</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I set realistic but challenging goals for practice.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>I say things to myself to help my practice performance.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>During practice I visualize successful past performances.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>My attention wanders while I am training.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>I practise using relaxation techniques at workouts</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>I practice a way to relax</td>
<td>1</td>
<td>2</td>
<td>3</td>
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<td>5</td>
</tr>
<tr>
<td>7</td>
<td>During competition I set specific result goals for myself</td>
<td>1</td>
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</tr>
<tr>
<td>8</td>
<td>When the pressure is on at competitions, I know how to relax</td>
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<td>2</td>
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<td>5</td>
</tr>
<tr>
<td>9</td>
<td>My self-talk during competition is negative</td>
<td>1</td>
<td>2</td>
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<tr>
<td>10</td>
<td>During practice, I don’t think about performing much - I just let it happen.</td>
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<tr>
<td>11</td>
<td>I perform at competitions without consciously thinking about it.</td>
<td>1</td>
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<tr>
<td>12</td>
<td>I rehearse my performance in my mind before practice.</td>
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<tr>
<td>13</td>
<td>I can raise my energy level at competitions when necessary.</td>
<td>1</td>
<td>2</td>
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<tr>
<td>14</td>
<td>During competition I have thoughts of failure.</td>
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<td>15</td>
<td>I use practice time to work on my relaxation technique.</td>
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<td>16</td>
<td>I manage my self-talk effectively during practice.</td>
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<td>17</td>
<td>I am able to relax if I get too nervous at a competition.</td>
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<td>18</td>
<td>I visualize my competition going exactly the way I want it to go.</td>
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<td>19</td>
<td>I am able to control distracting thoughts when I am training.</td>
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<td>20</td>
<td>I get frustrated and emotionally upset if practice does not go well.</td>
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<td>21</td>
<td>I have specific cue words or phrases that I say to myself to help my performance in competition.</td>
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<td>22</td>
<td>I evaluate whether I achieve my competition goals.</td>
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<tr>
<td>23</td>
<td>During practice, my movements and skills just seem to flow naturally from one to another.</td>
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<td>24</td>
<td>When I make a mistake in competition, I have trouble getting my concentration back on track.</td>
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<td>25</td>
<td>When I need to, I can relax myself at competitions to get ready to perform.</td>
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<td>26</td>
<td>I set very specific goals for competition.</td>
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<tr>
<td>27</td>
<td>I relax myself at practice to get ready.</td>
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<td>28</td>
<td>I psych myself up at competitions to get ready to perform.</td>
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<td>29</td>
<td>At practice, I can allow the whole skill or movement to happen naturally without concentrating on any part of the skill.</td>
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<td>30</td>
<td>During competition I perform on 'automatic pilot'.</td>
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<td>31</td>
<td>When something upsets me during a competition, my performance suffers.</td>
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<td>32</td>
<td>I keep my thoughts positive during competitions.</td>
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<td>33</td>
<td>I say things to myself to help my competitive performance.</td>
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<td>34</td>
<td>At competitions, I rehearse the feel of my performance in my imagination.</td>
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<td>35</td>
<td>I practice a way to energise myself.</td>
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<td>36</td>
<td>I manage my self-talk effectively during competition.</td>
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<td>37</td>
<td>I set goals to help me use practice time effectively.</td>
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<td>38</td>
<td>I have trouble energising myself if I feel sluggish during practice.</td>
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<td>39</td>
<td>When things are going poorly in practice, I stay in control of myself emotionally.</td>
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<td>40</td>
<td>I do what needs to be done to get psyched up for competitions.</td>
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<td>41</td>
<td>During competition, I don't think about performing much - I just let it happen.</td>
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<td>42</td>
<td>At practice, when I visualise my performance, I imagine what it will feel like.</td>
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<td>43</td>
<td>I find it difficult to relax when I am too tense at competitions.</td>
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<td>44</td>
<td>I have difficulty increasing my energy level during workouts.</td>
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<td>45</td>
<td>During practice I focus my attention effectively.</td>
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<td>46</td>
<td>I set personal performance goals for a competition.</td>
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<tr>
<td>47</td>
<td>I motivate myself to train through positive self-talk.</td>
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<tr>
<td>48</td>
<td>During practice sessions I just seem to be in a flow.</td>
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<tr>
<td>49</td>
<td>I practice energising myself during training sessions.</td>
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<tr>
<td>50</td>
<td>I have trouble maintaining my concentration during long practices</td>
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<tr>
<td>51</td>
<td>I talk positively to myself to get the most out of practice.</td>
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<td>5</td>
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<tr>
<td>52</td>
<td>I can increase my energy to just the right level for competitions.</td>
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<td>5</td>
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<tr>
<td>53</td>
<td>I have very specific goals for practice.</td>
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<tr>
<td>54</td>
<td>During competition, I play/perform instinctively with little conscious effort.</td>
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<td>5</td>
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<tr>
<td>55</td>
<td>I imagine my competitive routine before I do it at a competition.</td>
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<td>2</td>
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<td>5</td>
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<tr>
<td>56</td>
<td>I imagine screwing up during a competition.</td>
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<td>4</td>
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<tr>
<td></td>
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<tr>
<td>57</td>
<td>I talk positively to myself to get the most out of competitions.</td>
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<tr>
<td>58</td>
<td>I don't set goals for practices, I just go out and do it.</td>
<td></td>
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<tr>
<td>59</td>
<td>I rehearse my performance in my mind at competitions.</td>
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<tr>
<td>60</td>
<td>I have trouble controlling my emotions when things are not going well at practice.</td>
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<tr>
<td>61</td>
<td>When I perform poorly in practice I lose my focus.</td>
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<tr>
<td>62</td>
<td>My emotions keep me from performing my best at competitions.</td>
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<tr>
<td>63</td>
<td>My emotions get out of control under the pressure of competition.</td>
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<tr>
<td>64</td>
<td>At practice, when I visualise my performance, I imagine watching myself as if on a video replay.</td>
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</tbody>
</table>
PERFORMANCE PLAYER PROFILE

Please answer all questions as **honestly** and as **accurately** as possible. There are no right or wrong answers.

**THE QUESTIONNAIRE WILL REMAIN COMPLETELY CONFIDENTIAL**

YOUR SPECIFIC RESULTS WILL NOT BE SHARED WITH ANY OTHER PERSON

Thank you for your time and assistance. It is greatly appreciated.

Before you start we would like the following information from you.

**PERSONAL DETAIL**

Please fill out the information below about your past history:

1. **Gender (circle appropriately):**  
   - Male  
   - Female

2. **Year of Birth:** 

3. **Nationality:** 

4. **Sport:** 

5. **Years taking part in your sport:** 

6. **Years competing in your sport:** 

7. **What is your CURRENT level in your sport (tick/circle appropriately):**  
   - International  
   - National  
   - Regional  
   - School  
   - Club  
   - Recreational

Please begin on the next page
**ISCMS - PART A**

Taking part in competition can be quite a varied experience for all sports performers. Different people (e.g. coach, mother, father, other performers) are involved in shaping your experiences as an individual competitor. All of the following statements look at your experiences in competition, in your sport. We would like you to show as accurately as possible how the statements relate to your particular competition experiences.

**Directions:** The questionnaire is divided into five sections for each part of your competition experiences (e.g. how you are supported by: coach, father, mother, other performers). Each statement describes your experiences and asks the degree to which you generally believe these statements occur, from 'never occurs' to 'always occurs', in your typical competition environment. There are no right or wrong answers and they will not be shared with anyone so please answer as honestly as possible.

This next section is about your Coach. If you do not have a coach then please leave this section and move on to the next.

<table>
<thead>
<tr>
<th></th>
<th>Never Occurs</th>
<th>Sometimes Occurs</th>
<th>Always Occurs</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Before competition, my coach directs my attention to how I am going to produce my best skills.</td>
<td>1 2 3 4 5 6 7</td>
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<tr>
<td>2</td>
<td>My coach takes great care in looking back at how well I performed my skills.</td>
<td>1 2 3 4 5 6 7</td>
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<tr>
<td>3</td>
<td>My coach reminds me of the need to perform as best I can</td>
<td>1 2 3 4 5 6 7</td>
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<tr>
<td>4</td>
<td>My coach reminds me of the importance of my own personal level of achievements regardless of what opponents/other competitors achieve.</td>
<td>1 2 3 4 5 6 7</td>
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<tr>
<td>5</td>
<td>My coach looks back at my achievements in terms if how much I showed greater skills or strengths than my opposition.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
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<tr>
<td>6</td>
<td>Before I compete my coach spends time talking about how I can get the best out of myself.</td>
<td>1 2 3 4 5 6 7</td>
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<tr>
<td>7</td>
<td>My coach likes me when I improve in my own skills</td>
<td>1 2 3 4 5 6 7</td>
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<tr>
<td>8</td>
<td>Before competition, my coach reminds me of what I need to do to beat the opposition.</td>
<td>1 2 3 4 5 6 7</td>
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<tr>
<td>9</td>
<td>My coach talks to me about what strategies will help me to perform to the best of my ability.</td>
<td>1 2 3 4 5 6 7</td>
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<td></td>
<td>My coach sees my mistakes as a part of my performance improvement.</td>
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<tr>
<td>11</td>
<td>My coach spends time on what is required from me to perform better than others.</td>
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<tr>
<td>12</td>
<td>My coach makes it clear that s/he values the progress I make in the demonstration of my skills.</td>
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<tr>
<td>13</td>
<td>My coach lets me know the strong and weak points of my performance that he/she just watched.</td>
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<tr>
<td>14</td>
<td>My coach praises me when I am better than my opponent.</td>
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<td>15</td>
<td>My coach gives me the feeling that beating the opposition is something that is important for me to do.</td>
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<td>16</td>
<td>My coach views success or failure only in terms of whether I played or competed to the best of my ability</td>
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<td>17</td>
<td>My coach views mistakes as a natural part of learning</td>
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<td>18</td>
<td>My coach reminds me that giving my best effort is very important in competition.</td>
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<td>19</td>
<td>My coach ignores me if I don't win or beat particular opponents.</td>
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<td>20</td>
<td>My coach criticises me if I don't show higher ability than my opponent.</td>
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</table>

This section is about your Father/Step Father. Please fill in this section if it applies to you.

<table>
<thead>
<tr>
<th></th>
<th>Before competition, my father reminds me of the importance of doing my best.</th>
<th>1</th>
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<th>6</th>
<th>7</th>
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<tbody>
<tr>
<td>1</td>
<td>My father encourages me to review how I performed to help me learn from competition.</td>
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<td>2</td>
<td>My father is proud of me if I show greater skills or strengths than my opposition.</td>
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<td></td>
<td>Before performing, my father gives me the feeling that succeeding is about working hard, learning and showing that I have made progress.</td>
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<td>5</td>
<td>My father compares my performance with the performances of other players competitors.</td>
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<td>6</td>
<td>My father is concerned about whether or not I’m going to beat the opposition.</td>
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<td>7</td>
<td>My father is happy with me if I have tried despite the result.</td>
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<td>8</td>
<td>For me to beat an opponent is something that is important to him.</td>
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<td>9</td>
<td>My father views mistakes as part of learning</td>
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<td>10</td>
<td>My father gives me the feeling that being better than my opponents is something that is important to him.</td>
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<td>11</td>
<td>My father is a big believer in helping me to understand my strengths in order to make progress.</td>
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<td>13</td>
<td>Doing better than my opponents is important to my father, and this is reflected in what he says to me.</td>
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<td>14</td>
<td>My father is dissapointed in me if I do not put in 100% effort.</td>
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<td>15</td>
<td>My father is annoyed if I make a mistake when performing.</td>
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<tr>
<td>16</td>
<td>My father pays no attention to me if I give up trying my best.</td>
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</tbody>
</table>
This section is about your Mother or Step Mother. Please fill in this section if it applies to you.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Never Occurs</th>
<th>Sometimes Occurs</th>
<th>Always Occurs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Before competition, my mother reminds me of the importance of me</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>trying my best.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>My mother encourages me to review how I performed to help me learn</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>from competition.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>My mother is proud of me if I show greater skills or strengths</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>than my opposition.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>To my mother, success is about being better than your opponent</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>or other competitors.</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>5</td>
<td>Before performing, my mother gives me the feeling that succeeding</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>is about working hard, learning and showing that I have made</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>progress.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>My mother compares my performance with the performances of other</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>players competitors.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>My mother is concerned about whether or not I'm going to beat</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>the opposition.</td>
<td></td>
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<tr>
<td>8</td>
<td>For me to beat an opponent is something that is important to my</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>mother.</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>9</td>
<td>My mother views mistakes as part of learning</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>My mother gives me the feeling that being better than my</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>opponents is something that is important to her.</td>
<td></td>
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</tr>
<tr>
<td>11</td>
<td>My mother is a big believer in helping me to understand my</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>strengths in order to make progress.</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>12</td>
<td>My mother is keen to find out whether I played well or improved.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>My mother is the kind of person who just wants me to perform to</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
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<tr>
<td></td>
<td>the best of my ability.</td>
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</tr>
<tr>
<td>14</td>
<td>Doing better than my opponents is important to my mother, and</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
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<tr>
<td></td>
<td>this is reflected in what she says to me.</td>
<td></td>
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</tr>
<tr>
<td>15</td>
<td>My mother likes it when I improve my personal performance.</td>
<td>1 2 3 4 5 6 7</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Never Occurs</td>
<td>Sometimes Occurs</td>
<td>Always Occurs</td>
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<td>---</td>
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<td></td>
</tr>
<tr>
<td>1</td>
<td>My mother is dissapointed in me if I do not put in 100% effort.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>My mother rewards me only if I beat the opposition.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>My mother is annoyed if I make a mistake when performing.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This section is about people of your own age and includes your competitors, opponents and friends who play in tournaments.

<table>
<thead>
<tr>
<th></th>
<th>Never Occurs</th>
<th>Sometimes Occurs</th>
<th>Always Occurs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Being noticed by my opposition depends greatly upon whether I beat them or not.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Most performers concentrate on not losing and aren’t happy unless they win.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>My rivals and competitors take notice of me if I improve on an aspect of my performance.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Among my fellow sports performers, the higher the ranking, the more successful you are and the more recognition you receive.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>The first question that other competitors or rivals ask me is whether &quot;I won or lost&quot;.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Among my fellow competitors, I would receive praise for personal best times or showing real improvements.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Other competitors would congratulate me on a great performance and effort, even if I’d been beaten.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>My rivals/opponents are most interested in whether I win or lose, or what position I finished.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>I think that other competitors take more notice of you if you beat them.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
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<tr>
<td>10</td>
<td>Other competitors take notice of me when I get personal best times or for showing real improvements.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Other competitors don’t talk to me if I’ve lost.</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
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</tbody>
</table>
This section is about the sport component which refers to officials, how winning and losing is seen, and how people are picked for courses, camps and trips etc.

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</thead>
<tbody>
<tr>
<td>12</td>
<td>When I lose, the other competitors ignore me.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
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<tr>
<td>13</td>
<td>My friends avoid me if I do not beat my opponent/s.</td>
<td>1</td>
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<td>4</td>
<td>5</td>
<td>6</td>
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<tr>
<td>14</td>
<td>Other performers talk to me less if I have given up in competition.</td>
<td>1</td>
<td>2</td>
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<td>4</td>
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<th></th>
<th>Never Occurs</th>
<th>Sometimes Occurs</th>
<th>Always Occurs</th>
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<td>11</td>
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<tr>
<td>12</td>
<td>1</td>
<td>2</td>
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<tr>
<td></td>
<td>In my sport, you generally only get credit if you are better than the opposition.</td>
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<tr>
<td>13</td>
<td>1 2 3 4 5 6 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Only the top players 'get noticed' in my sport.</td>
<td></td>
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<tr>
<td>15</td>
<td>In my sport, being superior to an opponent is vital to gaining recognition.</td>
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</tbody>
</table>
ISCMS - PART B

As seen in the first section taking part in competition can be quite a varied experience
with different people (e.g., coach, mother, father, other performers) involved in shaping
your experiences as an individual competitor. All of the following statements look at your
experiences in competition, in your sport. We would like you to show as accurately as
possible how the statements relate to your particular competition experiences.

Directions: This part of the questionnaire looks at the influences of significant others
and the sporting reward structure on your competition experience. Each question asks
how much the person you are asked about (e.g. coach) affects your thoughts, feelings,
and behaviour in competition, from no affect/influence (not at all) to a high level of
affect/influence (very much). As before there are no right or wrong answers so please
answer as honestly as possible.

<table>
<thead>
<tr>
<th></th>
<th>How much does your coach affect your thoughts, feelings and behaviour in competition?</th>
<th>Not at all</th>
<th>Moderate</th>
<th>Very Much</th>
</tr>
</thead>
<tbody>
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<td>1</td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>How much does your father affect your thoughts, feelings and behaviour in competition?</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>How much does your mother affect your thoughts, feelings and behaviour in competition?</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>How much do other players affect your thoughts, feelings and behaviour in competition.</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>How much does the way that your sport rewards you as a performer affect your thoughts, feelings and behaviour in competition?</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>How much importance or value do you place on what your coach says to you before competition?</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>How much importance or value do you place on what your father says to you before competition?</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>How much importance or value do you place on what your mother says to you before competition?</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>9</td>
<td>How much importance or value do you place on what your friends or other competitors say to you before competition?</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>How much importance or value do you place on how your sport rewards you as a performer?</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
**SIMS**

**DIRECTIONS:** Read each item carefully. Using the scale below, please circle the number that best describes the reason why you are currently engaged in this activity.

Why are you currently engaged in playing/taking part in your sport?

<table>
<thead>
<tr>
<th></th>
<th>Exactly</th>
<th>Moderately</th>
<th>Not at all</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Because I think that my sport is interesting</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>Because I am doing it for my own good</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>Because I am supposed to do it</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>There may be reasons to play my sport, but personally I don't see them</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>Because I think that my sport is pleasant</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>Because I think that my sport is good for myself</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>Because it is something that I have to do</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>8</td>
<td>I play my sport but I am not sure if it is worth it</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>9</td>
<td>Because my sport is fun</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>10</td>
<td>By personal decision</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>11</td>
<td>Because I don't have a choice</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>12</td>
<td>I don't know; I don't see what my sport brings me</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>13</td>
<td>Because I felt good when playing my sport</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>14</td>
<td>Because I believe that my sport is good for me</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>15</td>
<td>Because I felt I had to do it</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>16</td>
<td>I play my sport but I am not sure it is a good thing to pursue.</td>
<td>7</td>
<td>6</td>
</tr>
</tbody>
</table>
**BASQ**

**DIRECTIONS:** Read each item carefully. Using the scale below, please circle the number that best describes what you think is the most likely to help players do well or succeed in sport?

<table>
<thead>
<tr>
<th>Players succeed if they:</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  Work really hard</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2  Are better athletes than the others</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3  Like to learn new things</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>4  Like to practice</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>5  Are born natural athletes</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>6  Like improving</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>7  Are better than others in tough competition</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>8  Help each other to improve</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>9  Stick to skills they are really good at</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>10 Always do their best</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>11 Always try to beat others</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>12 Help each other to learn</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
**POSQ**

**DIRECTIONS:** What does success in sport mean to you? There are no right or wrong answers. We ask you to circle the letter that best indicates how you feel.

**WHEN PLAYING/COMPETING IN COMPETITIONS IN MY SPORT I FEEL MOST SUCCESSFUL WHEN:**

<table>
<thead>
<tr>
<th></th>
<th>Strongly Agree</th>
<th>Neutral</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>3</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>4</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>5</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>6</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>7</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>8</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>9</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>10</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>11</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>12</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
</tbody>
</table>
Fluorimetric assay for the determination of blood lactate (modified from Maughan, 1982)

Principle:

\[ \text{NAD}^+ \xrightarrow{\text{NADH} + \text{H}^+} \text{Lactate dehydrogenase} \xrightarrow{\text{Pyruvate}} \]

Reagents:

Buffer: Hydrazine 1.1 mol·l⁻¹, pH 9.0 with 1 mmol·l⁻¹ EDTA-Na₂
Cofactor: NAD
Enzyme: lactate dehydrogenase (LDH) 5500 U·ml⁻¹ (undiluted)
Standard: L-Lactate 1 mol·l⁻¹ (stock solution)
Diluent: 0.07 mol·l⁻¹ HCl

Stock standards were prepared before each study and stored at -20°C:

<table>
<thead>
<tr>
<th>L-Lactate 1 mol·l⁻¹ (µl)</th>
<th>0</th>
<th>20</th>
<th>40</th>
<th>50</th>
<th>80</th>
<th>100</th>
<th>120</th>
<th>150</th>
<th>200</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4 mol·l⁻¹ perchloric acid (ml)</td>
<td>10</td>
<td>9.98</td>
<td>9.96</td>
<td>9.95</td>
<td>9.92</td>
<td>9.90</td>
<td>9.88</td>
<td>9.85</td>
<td>9.80</td>
</tr>
<tr>
<td>Lactate concentration (mmol·l⁻¹)</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>8</td>
<td>10</td>
<td>12</td>
<td>15</td>
<td>20</td>
</tr>
</tbody>
</table>

Working standards were prepared by diluting 20 µl of each of the above standards into 200 µl of 0.4 mol·l⁻¹ (~2.5%) perchloric acid.

Reaction mixture (final concentration):

Buffer 1 ml
NAD 2 mg (2.98 mmol·l⁻¹)
LDH 10 µl (54.46 U·ml⁻¹)

Quality Control:

A lyophilised protein matrix containing ~2.5 mmol·l⁻¹ lactate was used as a quality control in the assay. After reconstitution (by adding 5 ml of deionized water) the quality control solution was diluted 1:10 with 0.4 mol·l⁻¹ (2.5%) perchloric acid.

Procedure:

1. Samples and quality controls were thawed at room temperature for 60 minutes, mixed thoroughly and then centrifuged at 13000 revs.min⁻¹ for 3 minutes.
2. 200 µl of reaction mixture was added to 20 µl aliquots of duplicate samples, perchloric acid blanks, standards and quality controls. (Tubes were mixed well).
3. After 30 min incubation at room temperature, 1 ml of diluent (0.07 mol·l⁻¹ HCl) was added, the contents were mixed and fluorescence was read. Lactate concentration was calculated from the standard curve.