UNIVERSITY OF EXETER

PERCEIVED EXERTION RELATIONSHIPS IN ADULTS AND CHILDREN

Submitted by Danielle Lambrick to the University of Exeter as a thesis for the degree of Doctor of Philosophy in Sport and Health Sciences (March, 2010)

I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award a degree by this or any other University.

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Abstract

The ratings of perceived exertion are commonly employed within both a clinical and exercise setting to quantify, monitor and evaluate an individual's exercise tolerance and level of exertion. Recent advances in the area of perceived exertion have led to novel applications in the use of the ratings of perceived exertion scale as a means of predicting an individual's maximal functional capacity ($\dot{V}O_2$max) for exercise (Eston, Lamb, Parfitt, & King, 2005; Eston, Faulkner, Mason, & Parfitt, 2006; Eston, Lambrick, Sheppard, & Parfitt, 2008; Faulkner, Parfitt, & Eston, 2007). Yet the utility of such procedures with low-fit individuals or children has received little or no research attention. As such, one aim of this thesis was to assess the efficacy of the ratings of perceived exertion in predicting the $\dot{V}O_2$max of low-fit men and women, and healthy children. It is often presumed that like adults, a child's perception of exertion rises linearly with increases in exercise intensity, despite a limited amount research suggesting otherwise. Moreover, there is a lack of empirical evidence to suggest that children regulate their power output during a closed-loop exercise task in order to complete a given distance in the fastest time possible. Therefore, a further aim of this thesis was to explore the nature of the perceptual responses of young children across differing modes of exercise, and to examine whether children employ pacing strategies during running. In relation to this latter aim, it was of particular interest to explore pacing in relation to the ratings of perceived exertion during running, as the ratings of perceived exertion have been proposed as a key component of such a regulatory system during exercise (Tucker, 2009).

This thesis comprises a qualitative review of relevant literature, and six study chapters which were borne out of five empirical studies. The findings of studies 1 and 2 (chapters 3 & 4, respectively) support the utility of the ratings of perceived exertion to estimate $\dot{V}O_2$max in low-fit men and women, during cycle ergometry exercise.

Importantly, this has been shown from a single exercise test at a low-moderate exercise intensity, during either a step-incremental (study 1) or ramp-incremental (study 2) protocol. Studies 3 and 4 (chapters 5 & 6, respectively) provide evidence to suggest that a child's perception of exertion may rise linearly or curvilinearly in relation to increasing work, during either cycle ergometry or treadmill exercise. These studies support the utility of a unique, curvilinear, paediatric ratings of perceived exertion scale in obtaining accurate exertional responses from young children, across differing modes of exercise. In contrast to studies 1 and 2, study 5 (chapter 7) suggests that the novel means of predicting maximal functional capacity from submaximal ratings of perceived exertion in adults is inaccurate with young children. This was particularly evident in the low intraclass correlation coefficients and wide limits of agreement obtained between measured- and predicted $\dot{V}O_2max$, for both cycle ergometry and treadmill exercise. Study 6 (chapter 8) demonstrated that young children employ pacing strategies during an 800 m run, similar to adults, and that this improves with trial familiarisation. Moreover, the presence of other competitors has a detrimental effect on performance, particularly for girls.

Thesis Content

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Abbreviations

ACSM	American College of Sports Medicine
ANOVA	Analysis of Variance
$b{\cdot}min^{-1}$	Beats per minute
BABE	Bug And Bag Effort scale
BIA	Bioelectrical Impedance Analysis
CALER	Cart And Load Effort Rating scale
CERT	Children's Effort Rating Table
CR-10	Category Ratio-10 scale
DBP	Diastolic Blood Pressure
E-P scale	Eston-Parfitt RPE scale
GET	Gaseous Exchange Threshold
GXT	Graded-exercise Test
HR	Heart Rate
% HRmax	Heart rate expressed as a percentage of maximal heart rate
ICC	Intraclass Correlation Coefficients
$L{\cdot}min^{-1}$	Litres per minute
LoA	Limits of Agreement
m	Meters
min	Minutes
$ml{\cdot}kg^{-1}{\cdot}min^{-1}$	Millilitres per kilogram per minute
mmHg	Millimeters of mercury

n	Sample size
OMNI	Omnibus RPE scale
PCERT	Pictorial Children's Effort Rating Table
r	Pearson's correlation coefficient
R	Intraclass correlation coefficient
R^2	Coefficient of determination
rev·min^{-1}	Revolutions per minute
RPE	Ratings of Perceived Exertion
RR	Respiratory Rate
s	Seconds
SBP	Systolic Blood Pressure
SD	Standard Deviation
$\dot{V}CO_2$	Volume of Carbon Dioxide
$\dot{V}_E$	Ventilation
$\dot{V}O_2$	Volume of Oxygen Uptake
$\dot{V}O_2max$	Maximal Oxygen Uptake
$\dot{V}O_2peak$	Peak Oxygen Uptake
% $\dot{V}O_2max$	Oxygen uptake expressed as a percentage of maximal oxygen uptake
VT	Ventilatory Threshold
W	Watts
WR	Work Rate

Chapter 1

Introduction

Perceived exertion relates to the ability to detect and interpret the sensations that arise in the body during exercise, under conditions of effort, stress or discomfort (Noble & Robertson, 1996). However, perceived exertion per se is not a measurable construct; it requires the use of a defined scaling method to quantify the subjective evaluations of effort. Perhaps the most well-known scaling method of all is the Borg 6-20 ratings of perceived exertion (RPE) scale, which was developed in the 1960's by the pioneering research of Gunner Borg. The Borg 6-20 RPE scale is a valuable and reliable method to quantify, monitor and evaluate an individual's exercise tolerance and level of exertion, and is extensively used with both healthy and clinical populations alike (American College of Sports Medicine [ACSM], 2010; Borg, 1998).

Generally, the ratings of perceived exertion are used to assess exertional responses in relation to an *overall* perception of exertion, but may be differentiated into *local* (peripheral) and *central* (cardiorespiratory) sensations of exertion where applicable. The overall perception of exertion integrates sensory cues emanating from the cardiopulmonary system, the peripheral working muscles and joints, and from the higher centres of the brain (Robertson & Noble, 1997). Differentiated exertional signals provide a more concise definition of the physiological and / or symptomatic processes that shape the perceptual context during exercise (Noble & Robertson, 1996).

The ratings of perceived exertion frequently demonstrate a strong relationship with various physiological markers of exercise intensity, including oxygen uptake ($\dot{V}O_2$), heart rate (HR), and ventilation ($\dot{V}_E$), during differing modes of exercise. Often the RPE is employed within an exercise procedure as a means of passively *estimating* one's level of exertion, or for the purpose of actively *producing* a given exercise intensity. During an ‘estimation’ procedure, an individual rates their perception of exertion by assigning a number, according to a given ratings scale, that is proportional to their perceived sensation of effort. During a ‘production’ procedure, an individual must regulate their exercise intensity by adjusting their power output in order to maintain a prescribed RPE level. However, a further procedure, which is resultant upon the integration of the two aforementioned processes, is also commonly employed. The ‘estimation-production’ mode typically comprises an individual manipulating their exercise intensity to attain a prescribed RPE (production trial), which has been anchored to a physiological response (i.e. 70 % HRmax or $\dot{V}O_2$; BLa value), determined during a prior graded-exercise test (estimation trial; Williams & Eston, 1989). Familiarisation to the use of a ratings scale or an exercise procedure has shown to improve the reliability of the effort perceptions (Buckley, Eston & Sim, 2000; Eston & Williams, 1988). Recently, a novel application of the estimation-production procedure has been proposed by Eston & colleagues as a suitable means to predict maximal functional capacity, and to prescribe and monitor exercise intensity (Eston et al., 2005, 2006, 2008).

Several theoretical models have been proposed to regulate an individual’s power output (pacing strategy) during exercise, to ensure successful task completion whilst avoiding detrimental levels of fatigue (St Clair Gibson & Noakes, 2004; Tucker, 2009; Ulmer, 1996). Within these models, the ratings of perceived exertion are proposed to be a mediating factor in the setting of an appropriate pacing strategy. Yet, no definitive pacing strategy has been linked to a specific sport or distance performed within an athletic event (St Clair Gibson, Lambert, Rauch, Tucker, Baden, Foster, & Noakes, 2006).

1.1 Summary of thesis:

The aim of this thesis was to enhance current knowledge in the area of perceived exertion with both adults and children. This thesis is divided in its purpose; the first of three main objectives being to examine the efficacy of the ratings of perceived exertion in providing accurate predictions of maximal functional capacity ($\dot{V}O_2max$) in low-fit men and women - from either a step-incremental or continuous exercise protocol (studies 1 & 2, respectively) - and children (study 5). The findings of study 1 demonstrated that predictions of $\dot{V}O_2max$ were accurate (P > 0.05) when using the submaximal RPE from either an estimation or production procedure, or the Keele lifestyle RPE nomogram, for both men and women. There was also no statistical difference (P > 0.05) between measured- and predicted $\dot{V}O_2max$ from the Åstrand-Ryhming test, although larger mean differences were noted for women. However, relatively wide limits of agreement were noted between measured and predicted $\dot{V}O_2max$ for each of the predictive methods utilised. For study 2, no significant differences (P > 0.05) were observed between measured $\dot{V}O_2max$ (30.9 ± 6.5 $ml \cdot kg^{-1} \cdot min^{-1}$) and $\dot{V}O_2max$ predicted from submaximal RPEs reported prior to- and including an RPE 13 and the gaseous exchange threshold (GET; extrapolated to either an RPE 19 or 20), or from submaximal HR (equating to RPE 13 & GET). Predictions of $\dot{V}O_2max$ from an RPE 13 were most accurate, according to the limits of agreement and intraclass correlation analyses. Although a direct comparison was not made, the combined findings of studies 1 and 2 suggest that a continuous ramp-incremental protocol may facilitate more accurate estimates of $\dot{V}O_2max$, in low-fit men and women. To date, there is no published research on whether this novel application of the RPE can be used to estimate $\dot{V}O_2max$ in young children. As such, study 5 assessed the utility of the RPE in predicting $\dot{V}O_2max$ in children, during cycle ergometry and treadmill exercise. On the basis of the research findings, however, the employment of this procedure is not recommended with young children as this method may give rise to significant inaccuracy in predicting $\dot{V}O_2max$.

The second aim of this thesis was to explore the nature of the perceptual responses of children (aged 7 – 8 years) across differing modes of exercise (studies 3 & 4), using a newly-devised curvilinear ratings of perceived exertion scale (E-P scale; Eston & Parfitt, 2007). Investigation into the specific characteristics of the perceptual response, i.e. whether linear or curvilinear, in relation to several parameters (work rate, $\dot{V}O_2$, HR, $\dot{V}_E$) was central to this, as was the potential mediators of perceived exertion. Both studies 3 and 4 demonstrated that children may perceive exercise intensity in either a linear or curvilinear fashion in relation to increasing work, and that RPE is likely mediated by ventilatory and/or heart rate responses, during both cycle ergometry and treadmill exercise, respectively. Furthermore, the E-P scale was validated as an appropriate means of assessing perceived exertion responses in young children, across differing modes of exercise.

In the interest of assessing the perceived exertion responses of young children during field-based, self-paced exercise (as opposed to prescribed exercise protocols within a laboratory setting), study 6 of this thesis explored the ability of young, untrained children (aged 9-11 years) to employ pacing strategies during an 800 m running event on an outdoor athletics track. Furthermore, this study assessed whether trial familiarisation or level of competition influenced any adopted pacing strategy. The findings of study 6 suggest that untrained children inherently pace themselves during an 800 m running event, despite no prior familiarisation to the exercise task. Moreover, repeated trials may enhance exercise performance through refinements in the adopted pacing strategy, but a competitive situation may in fact be detrimental to a recently learned pacing strategy, and thus overall exercise performance. The ratings of perceived exertion (E-P scale) were shown to differ slightly between laboratory and field-based exercise tasks for a comparable physiological cost, but remained consistent throughout the repeated field-based trials. This finding adds further support to the utility of the ratings of perceived exertion in assessing exercise effort in young children, during both laboratory and field-based exercise tasks.

Overall, this thesis provides substantial evidence in support of the ratings of perceived exertion as a valid means of assessing perceived exertion in both adults and children, and in prescribing exercise with men and women of low-fitness. The novel application of the RPE for predicting maximal functional capacity (Eston et al., 2005) has been shown to be valid for low-fit men and women, but not young children. Perceived exertion has been shown to rise in both a linear and curvilinear fashion with increasing work in young children, and such a response may be mediated by physiological changes, particularly in ventilation and heart rate. Furthermore, this thesis has demonstrated that young, untrained children employ pacing strategies during field-based exercise, and that this may improve with trial familiarisation. However, level of competition may prove detrimental to exercise performance. Nevertheless, the ratings of perceived exertion have proved a reliable means of assessing exercise effort across both laboratory and field-based exercise trials, regardless of the competitive nature of the exercise task, in children aged 9-11 years.

Chapter 2

Review of Literature

2.1. Perceived Exertion:

Perceived exertion may be defined as the act of detecting and interpreting various sensations which may arise from the body during physical exercise. This may include the subjective intensity of effort, discomfort, strain and fatigue (Borg, 1962; Noble & Robertson, 1996). The overall perception of exertion is a *gestalt* of sensations (Borg, 1998), integrating somatosensory cues from the peripheral muscles and joints, cardiopulmonary system, and neurosensory pathways associated with the higher centres of the brain (Robertson & Noble, 1997). Other sociological- or psychological factors related to emotional state and prior exercise experience, among others, may also systematically influence the perception of exertion (Morgan, 2001; Noble & Robertson, 1996). Indeed, the perception of exertion during exercise is regarded as an active process, wherein physiological, cognitive and behavioural functions act to modulate the intensity of the perceptual signal relative to the exercise demand (Noble & Robertson, 1996; Rejeski, 1985).

The perception of exertion has been extensively studied since the end of the 1950's. Initial research utilised Stevens' (1957) newly-developed ratio scaling methods in order to determine stimulus (S) – response (R) functions of effort perception. The first psychophysical studies investigating subjective force and perceived exertion identified psychophysical growth functions between perceived intensity and physical work load that varied dependent upon exercise modality (Borg, 1970, 1982; Borg & Dahlström, 1960). Generally, exponents of ~1.6 (Borg & Dahlström, 1959; Borg, Edström, & Marklund, 1970) and ~3 (Borg, 1973b, 1998) have been obtained during cycle ergometry and treadmill exercise, respectively. Borg proposed that during physical and mental work (effort stimulus), an individual's overall effort response is shaped through the integration of differing objective and subjective stress indicators (Borg & Noble, 1974). It is these stress indicators that constitute Borg's three effort continua: physiological, perceptual, and performance.

2.2. Three-effort continua:

The effort continua encapsulate the interdependence between the physiological demands of performing an exercise task and the perception of effort that is associated with that performance (Robertson, 2004).

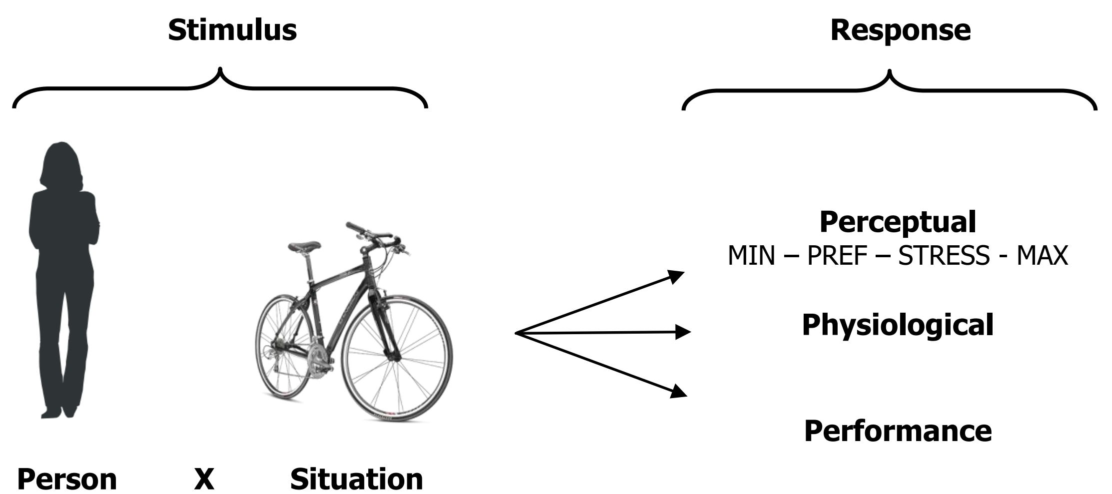

Figure 2.1. Borg's three effort continua: perceptual, physiological and performance. *Note:* Modified from Borg, G. (1998). *Borg's Perceived Exertion and Pain Scales*, p. 6.

In this model, the perceptual response (i.e. the perceived degree of strain) provides much of the same information regarding the exercise performance as do selected physiological variables (Robertson & Noble, 1997). As such, certain characteristics of a performance (i.e. intensity; duration) can be modified on the basis of this functional interaction between the physiological and perceptual continua. The physiological continuum proposes that a number of physiological variables contribute to the overall perception of exertion, including, but not limited to heart rate (HR), oxygen uptake ($\dot{V}O_2$), ventilation ($\dot{V}_E$), respiratory rate (RR), blood and muscle lactate, catecholamine secretion, muscle glycogen, and skin or core body temperature (Borg, 1998). Although objective measurement of each of these variables is simple, the independent growth functions must be considered in relation to the stimulus intensity. Namely, HR and $\dot{V}O_2$ are known to rise linearly with corresponding increases in exercise intensity whereas $\dot{V}_E$ and blood lactate rise according to a positively accelerating function. The perceptual continuum trusts that perception plays an essential role in shaping our behaviour and response to an external situation or event. It is fundamental in the sense that an individual's subjective experience will dictate their understanding, and the meaning behind the concept of perceived exertion (Borg, 1998). In this regard, psychosocial factors including emotional / mood state, cognitive function, situational attributes, or other more specific perceptions such as pain tolerance and the somatosensory system impact on the perceptual continuum during exercise (Morgan, 2001). The performance continuum involves the complex interplay between situational characteristics (i.e. exercise mode; environment) and corresponding physiological and perceptual responses, regardless of the intensity of physical work (minimum, preferred, stress, maximal).

In essence, perceived exertion is a multidimensional construct, and it is the functional interdependence of physiological and behavioral responses to physical work that forms the underlying rationale of the Ratings of Perceived Exertion (RPE; Robertson, 2004). A progression of Borg's early work was the development of several psychophysical category RPE scales to quantify subjective sensations of effort associated with various physical activities. Arguably, the most commonly employed perceptual ratings scale of all is the Borg 6-20 RPE scale.

2.3. Adult Ratings of Perceived Exertion scales:

2.3.1. Borg 6-20 Scale:

The Borg 6-20 RPE scale is a valid and reliable means to assess an individual's exercise tolerance and level of exertion during exercise or to prescribe optimal training intensities (ACSM, 2010; Mahon & Marsh, 1992). The 15-point RPE scale, which has been described as an equidistant interval scale (Borg, 1998), incorporates nine verbal descriptors of effort that extend from 'no exertion at all' to 'maximal exertion' on a corresponding numerical range from 6 to 20. The underlying rationale for the development of the 6-20 RPE scale was to improve the linearity between perceived exertion and workload during cycle ergometry exercise (Borg, 1982). Furthermore, as HR and $\dot{V}O_2$ rise as a similar function of work rate, this also permits comparisons between the RPE and HR / $\dot{V}O_2$ throughout exercise. The scale values 6 to 20 were loosely based around a 'typical' HR range of 60-200 $b \cdot min^{-1}$, as observed in prior studies on healthy, middle-aged men & women, with each rating intended to denote a given HR when multiplied by a value of 10 (HR = RPE x 10; Borg, 1998). The RPE:HR equation was designed to facilitate the use of the scale, whilst it was not intended to be taken too literally given that submaximal HR as an indicator of strain may be influenced by several factors (environmental, behavioural & dietary, age or mode of exercise; ACSM, 2010; Borg, 1982).

6	**No exertion at all**
7	**Extremely light**
8	
9	**Very light**
10	
11	**Light**
12	
13	**Somewhat hard**
14	
15	**Hard (heavy)**
16	
17	**Very hard**
18	
19	**Extremely hard**
20	**Maximal exertion**

Figure 2.2. The Borg 6-20 Rating of Perceived Exertion Scale. *Note*: Modified from Borg, G. (1998). *Borg's Perceived Exertion & Pain Scales,* p. 31.

During an exercise session, estimates of perceived effort are obtained at specific time-points by participants stating or pointing to a number on the RPE scale that equates their current level of exertion. Clear, concise written and verbal scale instructions should be provided to aid interpretation of the sensations of exertion (ACSM, 2010).

2.3.2. Additional ratings scales:

In addition to the 6-20 RPE scale, several other ratings scales have been devised for use with adults. These include the Category-Ratio 10 (CR-10; Borg, 1982; Ljunggren, 1986; Ljunggren & Johansson, 1988; Noble, Borg, Jacobs, Ceci, & Kaiser, 1983), CR-20 (Borg, Hassmén, & Lagerström, 1987; Hassmén, 1990), and CR-100 (Borg & Borg, 2002) scales. The original CR-10 scale was designed to assess physiological responses, specifically pulmonary ventilation, or blood and muscle lactate, that rise according to a positively accelerating power function in relation to physical work (Noble, 1982). More recently, Robertson and colleagues have devised several mode-specific versions of the Omnibus (OMNI) scale of perceived exertion. These include the adult OMNI-cycle (Kang, Hoffman, Walker, Chaloupka, & Utter, 2003; Robertson et al., 2004), OMNI-walk/run (Kang et al., 2003; Utter et al., 2004b), OMNI-resistance (Lagally & Robertson, 2006) and OMNI-Kayak scales (Nakamura et al., 2009). Alternatively, the Estimation of Time Limit (ETL; Garcin, Vandewalle, & Monod, 1999) or Visual Analogue Scales (VAS; Neely, Ljunggren, Sylven, & Borg, 1992: Ueda, Nabetani, & Teramoto, 2006) may be used to assess perceptual responses in adults. Several important advancements have also occurred in the study of effort perception in children over the last 20 years (Lamb, Parfitt, & Eston, 2008).

2.4. Paediatric Ratings of Perceived Exertion Scales:

Initial investigative efforts utilised the Borg 6-20 RPE scale to assess perceived exertion in children (Bar-Or, 1977; Eston & Williams, 1986; Mahon & Marsh, 1992; Miyashita, Onodera, & Tabata, 1986; Ward, Blimkie, & Bar-Or, 1986; Ward, Jackman, & Gallano, 1991; Williams, Eston, & Stretch, 1991). Other investigations have utilised the scale for the purpose of controlling, or regulating exercise intensity (Eston, Lamb, Bain, Williams, & Williams, 1994; Lamb, 1996; Lamb, Eaves, & Hartshorn, 2004; Preston & Lamb, 2005; Robertson et al., 2002; Ward & Bar-Or, 1990; Ward et al., 1991; Ward, Bar-Or, Longmuir, & Smith, 1995; Williams et al., 1991; Williams, Eston, & Furlong, 1994; Yelling, Lamb, & Swaine, 2002). Although several of the aforementioned authors have reported relative success in employing the scale with children, it is evident that the extent of a child’s personal experience in completing exertional tasks perceptibly impacts upon their ability to evaluate their perception of exertion (Bar-Or, 1977; Bar-Or & Ward, 1989; Lamb et al., 2008). In this regard, the ability of older children and adolescents to perceive exercise effort accurately has shown to be comparable to that of adults (Eston & Williams, 1986;

Miyashita et al., 1986). Conversely, Bar-Or (1977) suggests that children under 16 years of age are less competent at using the RPE than adults (18^+ years). Miyashita et al. (1986) further proposed that a critical age for understanding and employing the Borg 6-20 scale effectively is 9-years old. Yet, previous research has demonstrated that younger children (8 – 14 years) can competently produce differing levels of exertion according to the RPE (Ward et al., 1991; Williams et al., 1991). In light of such conflicting beliefs, it is likely that the cognitive developmental level and reading ability of a child, coupled with the degree of prior practice of the required skill, has greater influence over their ability to use the RPE than simply chronological age (Bar-Or & Ward, 1989; Lamb et al., 2008; Parfitt, Shepherd, & Eston, 2007).

Nystad, Oseid, & Mellbye, (1989) were the first authors to attempt to improve children's understanding of the Borg 6-20 RPE scale through the addition of pictorial descriptors; a concept that was advocated by Bar-Or & Ward (1989). Yet the children in their study continued to experience difficulties in interpreting the scale to estimate and produce exercise effort. The authors attributed this to the children's comparatively underdeveloped cognitive ability. Following a suggestion by Williams et al. (1991) that a more 'meaningful' 1-10 scale would be more appropriate for assessing perceived exertion in children, the authors developed and validated the Children's Effort Rating Table (CERT; Eston et al., 1994; Williams et al., 1994).

2.4.1. Children's effort rating table (CERT):

The CERT uses a narrower numerical range with numbers that are deemed more familiar to a child, and verbal anchors which were generated by children.

1	**Very, Very Easy**
2	**Very Easy**
3	**Easy**
4	**Just Feeling a Strain**
5	**Starting to Get Hard**
6	**Getting quite Hard**
7	**Hard**
8	**Very Hard**
9	**Very, Very Hard**
10	**So Hard I'm Going to Stop**

Figure 2.3. Children's Effort Rating Table (CERT). *Note*: Modified from Eston et al. (1994). Validity of a perceived exertion scale for children: a pilot study, p. 693.

Similar to the original design of the 6-20 RPE scale, the numerical range of the CERT was based upon a conceptual model wherein HR (in the range 100 to 200 $b \cdot min^{-1}$) and perceived effort are linearly related according to the equation: HR = 100 + 10x; where x is the CERT value reported at any given time (Eston et al., 1994). Greater validity has been noted for the CERT when compared against the traditional RPE scale with children aged 8 – 11 years (Leung, Chung, & Leung, 2002). The development of the CERT is considered to be a significant advancement in the study of perceived exertion in children (Bar-Or & Rowland, 2004; Mahon, 1997; Robertson & Noble, 1997).

2.4.2 Advances in paediatric effort perception:

More recently, a number of derivatives of the 10-point scale have been developed to incorporate simplified numerical-, verbal- and pictorial descriptors of perceived exertion, which may be readily assimilated by a child based upon their prior learning and experience (Lamb et al., 2008). Abridged and pictorial versions of the CERT include the Cart and Load Effort Rating (CALER) Scale (Eston, Parfitt, Campbell, & Lamb, 2000) that depicts a child pulling a cart along flat terrain which is progressively laden with bricks, and the Bug and Bag Effort (BABE) Scale (Parfitt et al., 2007), which portrays a Disney animation of an ant performing a stepping exercise onto a bench whilst wearing a backpack of increasing load.

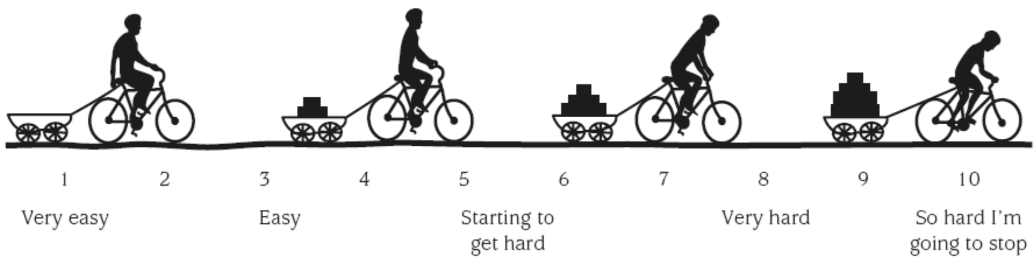

Figure 2.4. Cart and Load Effort Rating scale (CALER). *Note*: Reprinted with permission from Eston et al. (2000). Reliability of effort perception for regulating exercise intensity in children using the Cart and Load Effort Rating (CALER) Scale, p. 390.

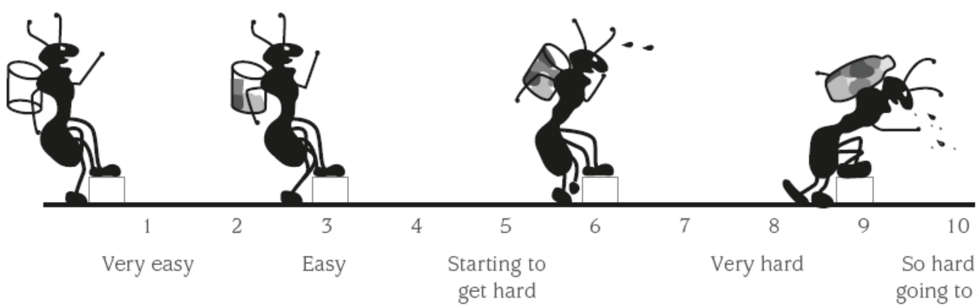

Figure 2.5. Bug and Bag Effort (BABE) scale. *Note*: Reprinted with permission from Parfitt et al. (2007). Reliability of effort perception using the children's CALER and BABE perceived exertion scales, p. 50.

In both of these aforementioned scales, the sequential increases in bricks or 'load' are commensurate with the numbers on the linear scale. Additionally, the verbal anchors incorporated into both the CALER and BABE scales were specifically chosen from the original phrases used in the CERT (Lamb et al., 2008).

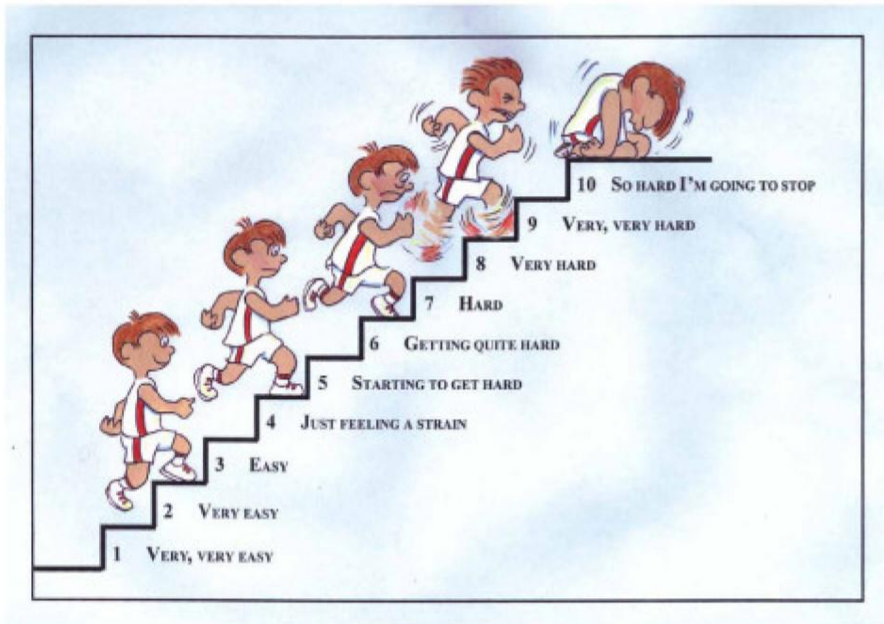

Figure 2.6. Pictorial Children's Effort Rating Table (PCERT). *Note*: Reprinted with permission from Yelling et al. (2002). Validity of a pictorial perceived exertion scale for effort estimation and effort production during stepping exercise in adolescent children, p. 161.

A further pictorial version of the CERT (P-CERT; Yelling et al., 2002) uses all 10 original verbal descriptors of the CERT and depicts a child in five stages of exertion ascending a flight of steps. The PCERT is regarded as an important progression from the original CERT (Lamb et al., 2008).

The Omnibus (OMNI) cycle scale (Robertson et al., 2000a) utilises a similar numerical response continuum of 0-10 and contains four illustrations of a child riding a bicycle up a 45˚ incline.

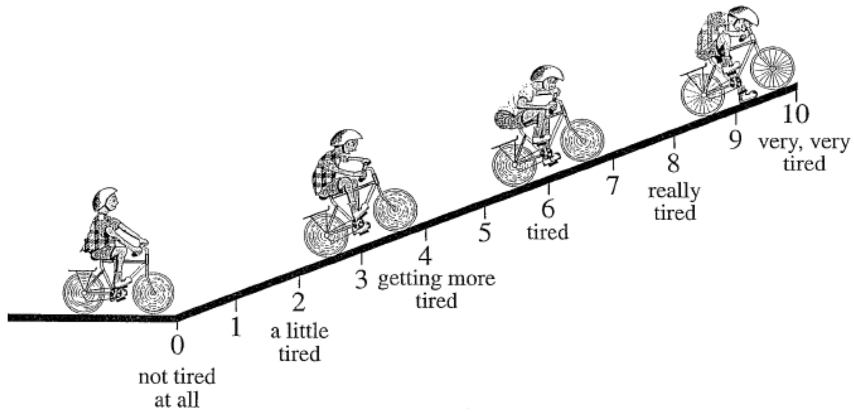

Figure 2.7. Omnibus (OMNI) cycle scale. *Note*: Reprinted with permission from Robertson et al. (2000a). Children's OMNI scale of perceived exertion: Mixed gender and race validation, p. 453.

Several derivatives of the OMNI-cycle scale have been developed for use with children, including the OMNI-walk/run scale (Utter, Robertson, Nieman, & Kang, 2002b), OMNI-step scale (Robertson et al., 2005b) and OMNI-resistance scale (Robertson et al., 2005a). A more recent pictorial version of the Borg 6-20 RPE Scale has also been developed for use with young children. The RPE-C scale (Groslambert, Hintzy, Hoffman, Dugue, & Rouillon, 2001) depicts a character in various stages of exertion on a vertical numerical scale.

2.4.3. Novel curvilinear paediatric ratings scale:

On the theoretical basis that children will readily conceive that *the steeper the hill, the harder it is to ascend* (Lamb et al., 2008), a pictorial scale that depicts a curvilinear relationship rather than a linear relationship between the RPE and exercise intensity has recently been proposed to assess RPE in young children (Eston & Parfitt, 2007; Faulkner & Eston, 2008).

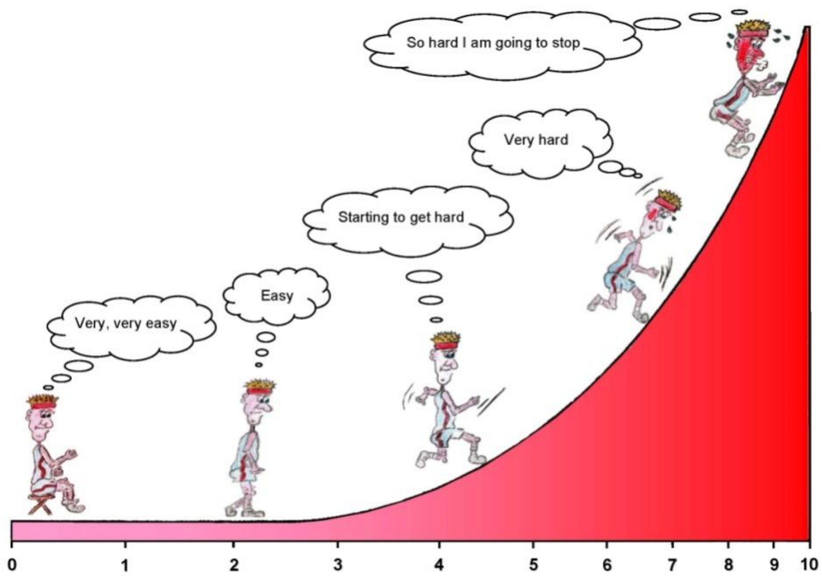

Figure 2.8. Eston-Parfitt (E-P) scale. *Note*: Modified from Eston, R.G., & Parfitt, G. (2007). Perceived Exertion. In N. Armstrong (Ed.), *Paediatric Exercise Physiology*, p. 290.

The Eston-Parfitt (E-P) scale depicts an ambulatory figure at various stages of exertion on a concave slope with a progressively increasing gradient at the higher intensities. The numerical range (0-10) reflects the disproportionate increase in the line's gradient, as evidenced by a reduction in the distance between each numbered increment on the horizontal axis in relation to its antecedent, and verbal anchors are abridged from the Children's Effort Rating Table (CERT; Eston et al., 1994; Williams et al., 1994). The area under the curve is also progressively shaded from light to dark red from left to right, respectively. The E-P scale is a category scale that contains ratio properties, similar to the Borg CR-10 scale, which allows inter-individual comparisons of perceptual responses to be made. The scale instructions also encourage ratings with decimals between the anchors, akin to the commonly employed CR-10 scale. Yet, unlike the aforementioned linear ratings scales, the validity of the E-P scale is yet to be confirmed.

2.5. Physiological mediators of perceived exertion:

The Borg 6-20 RPE scale has been continually assessed and validated against a number of physiological variables in adults, across differing exercise modes. It has been suggested that children may be more perceptually sensitive to changes in physiological effort than adults (Bar-Or, 1977). As such, the aforementioned child-specific RPE scales have also been shown to possess concurrent validity in prepubescent children and adolescents, as demonstrated by their strong association with various cardiorespiratory measures.

2.5.1. Relationship between RPE and heart rate (HR) in adults:

The Borg 6-20 RPE scale was devised to educe a positive linear relationship between perceived exertion and HR during light to heavy exercise, at a ratio of 1:10 (Borg, 1982). Borg’s initial efforts at validating the RPE scale yielded a correlation coefficient of $r = 0.85$ between the RPE and HR (Borg, 1962). Accordingly, numerous studies have since reported moderate to strong linear correlation between these two variables, which have ranged from $r = 0.52 – 0.98$ under a variety of conditions. This has been shown for cycle ergometry (Borg, 1973a; Ekblom & Goldbarg, 1971; Eston & Williams, 1986; Gamberale, 1972; Leung, Leung, & Chung, 2004; Morgan & Borg, 1976; Ward et al., 1991), treadmill walking and running (Bar-Or, Skinner, Buskirk, & Borg, 1972; Ekblom & Goldbarg, 1971; Skinner, Hustler, Bersteinova, & Buskirk, 1973; Smutok, Skrinar, & Pandolf, 1980; Ward et al., 1991), arm ergometry (Borg et al., 1987; Ekblom & Goldbarg, 1971; Ward et al., 1995), rowing ergometry (Marriott & Lamb, 1996), kayaking (Diafas et al., 2007), swimming (Ekblom & Goldbarg, 1971; Kurokawa & Ueda, 1992), resistance exercise (Gamberale, 1972), and wheelchair exercise (Ward et al., 1995). Research has previously shown a linear relation between HR and the RPE irrespective of age (Gillach, Sallis, Buono, Patterson, & Nader, 1989), gender (Skinner, Borg, & Buskirk, 1969; Skinner et al., 1973; Stamford, 1976), level of fitness (Bar-Or et al., 1972; Mihevic, 1983), or environmental temperature (Skinner et al., 1973).

Despite the significant sum of correlational data that exists however, it is pertinent to recognise that a causal relationship between HR and the RPE cannot be assumed (Noble & Robertson, 1996). In this regard, several studies, often using experimental manipulation to perturb normal HR response, challenge the relative importance of HR as a primary physiological mediator of the respiratory-metabolic signals of exertion (Glass, Knowlton, & Becque, 1992; Hampson, St Clair Gibson, Lambert, & Noakes, 2001). Utilising parasympathetic (atropine) and sympathetic (propranolol) blocking agents to alter autonomic nervous system activity, Ekblom & Goldbarg (1971) assessed changes in the RPE in relation to HR during cycle ergometry exercise. The authors asserted that for a given submaximal $\dot{V}O_2$, the RPE response in either the *atropine* or *propranolol* conditions were not statistically different in relation to the control values; however, the relationship between RPE and HR across experimental conditions was significantly altered. Comparable findings have been reported in a similar study investigating the effects of atropine and practolol on the HR:RPE relationship (Davies & Sargeant, 1979). The RPE has shown to be independent of HR during conditions of heat stress or reduced heat loss (Gamberale & Holmer, 1977; Pandolf, Cafarelli, Noble, & Metz, 1972). Furthermore, as maximal HR is known to decline with age, older subjects consistently report a greater RPE for a given submaximal HR than their younger counterparts (Bar-Or, 1977; Borg & Linderholm, 1967). The linearity in the relationship between HR and the RPE has also shown to be stronger in men than in women (Arstila, Antila, Wendelin, Vuori, & Valimaki, 1977).

As concomitant changes in the RPE are not always observed with alterations in the HR response, it is unlikely that HR is a parameter which is consciously monitored during exercise (Robertson, 1982). Nevertheless, it has been suggested that differing hemodynamic responses, such as cardiac output, stroke volume, or blood pressure, may provide strong central signals of exertion (Mihevic, 1981).

2.5.2. Relationship between RPE and heart rate (HR) in children:

For any given HR (or % HRmax), children have a tendency to under-rate their perception of effort relative to adolescents or adults (Bar-Or, 1977; Lamb, 1995; Mahon & Marsh, 1992; Ward et al., 1991). As such, the theoretical RPE:HR ratio of 1:10 for adults, which is inherent to the design of the RPE scale, may not be applicable for children. Ratios of 0.7:10 and 0.8:10 have been reported between the RPE and HR for 10- and 13-year old boys, respectively, suggesting that changes in this ratio may be a function of age (Bar-Or, 1977). One exception which has been noted in the literature however is that of 7 – 9 year old gymnasts with which a 1:10 ratio has been shown to be appropriate, but without given reason (Bar-Or, 1977). It is also of interest to note that increases in the RPE: HR ratio has been shown to correspond with increases in exercise intensity (Lamb, 1995). Yet, a decline in the RPE: HR ratio has been observed during heat acclimatisation, or physical conditioning programmes in 8 – 10 year-old children (Bar-Or, 1977).

Similar to the studies with adults, a cause-and-effect relationship cannot be assumed between HR and RPE in children. Yet the accuracy or validity of ratings scales relies on the strength of the association between these two variables (Bar-Or & Ward, 1989). Correlation coefficients between RPE and HR are generally reported to be higher in healthy children and adolescents than adults, when utilising the Borg 6-20 scale (Bar-Or, 1977). In this regard, a strong, positive relationship between the RPE and HR has also been reported for wheelchair users, irrespective of activity status (Ward et al., 1995). However, no correlations were provided in this study, and the participant sample comprised of both adults and children (range: 11 – 30 years).

a) Estimation Procedures:

Across differing estimation protocols, correlations for the RPE and % HRmax have shown to range from *r* = 0.55 - 0.94 for children aged 7 – 18 years (Miyashita et al., 1986; Pfeiffer, Pivarnik, Womack, Reeves, & Malina, 2002). A strong correlation (*r* = 0.98) has also been reported between the RPE and HR for both cycle ergometry and treadmill exercise in 10 year-old boys (Duncan, Mahon, Gay, & Sherwood, 1996). However, correlations are slightly reduced when employing a Cantonese (Chinese-translated) version of the Borg scale during cycle ergometry exercise, ranging from *r* = 0.69 - 0.71 and *r* = 0.58 - 0.73 for Hong Kong boys and girls aged 10 – 11 years, respectively (Leung et al., 2002). In the same study, these authors reported more favourable correlations of *r* = 0.82 - 0.84 and *r* = 0.88 - 0.90 for HR and RPE using a Cantonese version of the CERT. Generally, correlations for the CERT with HR range from *r* = 0.73 - 0.99 during cycling or stepping exercise, with girls and boys aged 6 – 11 years (Eston et al., 1994; Lamb, 1995; Williams, Furlong, Hockley, & MacKintosh, 1993; Williams et al., 1994). Concurrent increases in the RPE with submaximal HR have been observed when employing the CALER scale during cycle ergometry with 9 year-old children (*r* = 0.92; Barkley & Roemmich, 2008). A strong linear relationship has been reported between the RPE (PCERT) and HR during submaximal treadmill exercise, regardless of gender (*r* = 0.73 - 0.92; Marinov, Mandadjieva, & Kostianev, 2008; Roemmich et al., 2006). Variable correlations have been demonstrated for the RPE with HR when using the OMNI walk/run scale (*r* = 0.26 - 0.92; Roemmich et al., 2006; Suminski, Robertson, Goss, & Olvera, 2008, Utter et al., 2002b), OMNI-cycle scale (*r* = 0.86 - 0.93; Robertson et al., 2000a; Barkley &

Roemmich, 2008) or OMNI-step scale of perceived exertion (*r* = 0.86, Robertson et al., 2005b). A correlation of *r* = 0.86 has also been reported for the OMNI bike RPE with %HRmax in a sample of adolescent girls (13 – 18 years) during treadmill exercise (Pfeiffer et al., 2002).

b) Production Procedures:

In addition to the above studies which reported RPE during an estimation paradigm (see 2.7.1) the strength of the relationship between the RPE and HR has shown to vary during the production mode (see 2.7.2). A modest correlation of *r* = 0.54 - 0.61 has been reported between the RPE and HR for children aged 9 – 10 years when the Borg 6-20 RPE scale was used to regulate exercise intensity across four stages of a discontinuous cycle ergometry protocol (Lamb, 1996). A slightly, but non-significantly lower correlation of *r* = 0.47 was also reported in this study for the CERT with HR (Lamb, 1996). Parfitt et al. (2007) have shown high intraclass correlations (*R*) for HR (*R* = 0.90 & *R* = 0.87) for cycling and stepping exercise, respectively, when the BABE scale was used as the independent variable to regulate exercise intensity at RPE 3, 5 and 8 in a triple-repeated, randomised, intermittent production paradigm.

c) Evidence for a curvilinear relationship between HR and RPE in children:

Despite considerable evidence to suggest a linear relationship between HR and RPE in children as in adults, some studies report a disparity in this relationship, particularly at the higher intensities of exercise (Barkley & Roemmich, 2008; Lamb, 1995; Roemmich et al., 2006). Using the CERT in a passive estimation mode, Lamb (1995) noted a non-linear trend in the RPE with the HR data of 36 boys and girls, aged 9 – 10 years, which was particularly prevalent at the higher intensities of exercise. Accordingly, a curvilinear model was proposed to fit this data more suitably, and yielded stronger correlations than the original linear model. Indeed, in a pilot study for the curvilinear E-P scale, Eston & Parfitt (2007) revealed moderately-high intraclass correlation coefficients (ICC) of *R* = 0.71, 0.75 and 0.76 between HR and the RPE, in boys and girls aged 8 – 11 years.

2.5.3. Relationship between RPE and absolute oxygen uptake ($\dot{V}O_2$) in adults:

Several investigators have suggested that $\dot{V}O_2$ may provide a strong central sensory cue for the perception of exertion during exercise. A strong linear relationship has been demonstrated between the RPE and $\dot{V}O_2$, with correlations ranging from r = 0.76 - 0.99 during continuous and intermittent exercise tasks (Edwards, Melcher, Hesser, Wigertz, Ekelund, 1972; Ekblom & Goldbarg, 1971; Eston et al., 2005, 2006, 2008; Glass et al., 1992; Sargeant & Davies, 1973; Smutok et al., 1980). A more modest correlation (r = 0.63) has been reported in a meta-analytical study (Chen, Fan, & Moe, 2002). Although the authors reported validity coefficients that were higher for men (r = 0.83) than women (r = 0.12), it has previously been demonstrated that the RPE:$\dot{V}O_2$ relationship exists irrespective of gender (Eston et al., 2006). It is noteworthy that the mean correlations reported in the aforementioned meta-analysis are derived from a varying number of studies (women: n = 2; men: n = 21) and from studies that differ in experimental design (sample size, exercise mode, exercise protocol), which may account for the differences in the research findings.

Despite the strong correlational evidence, it has been suggested that $\dot{V}O_2$ is indirectly related to RPE, and is not a parameter that is consciously monitored during exercise (Carton & Rhodes, 1985; Mihevic, 1981; Roberston, 1982). This has been proposed following manipulations to pedal frequency (Pandolf & Noble, 1973), or environmental conditions (hyperoxia cf. normoxia; Pedersen & Welch, 1977). Ekblom &

Goldbarg (1971) demonstrated that for a given absolute submaximal $\dot{V}O_2$, the RPE are higher during cycle ergometry than for running, and higher still for arm work than for leg work. Individual differences between the RPE and $\dot{V}O_2$ have been observed between one- and two-leg exercise tasks (Sargeant & Davies, 1973, 1977). Differences in perceptual responses at absolute exercise intensities have also been observed in individuals of differing body composition (Skinner et al., 1973), fitness level (Skinner et al., 1969), or training status (Ekblom & Goldbarg, 1971). On this basis, it is unlikely that absolute $\dot{V}O_2$ is a primary factor influencing the perception of effort during exercise (Carton & Rhodes, 1985; Pandolf & Noble, 1973).

a) Relationship between RPE and relative oxygen uptake (% $\dot{V}O_2max$) in adults:

Relative exercise intensity (% $\dot{V}O_2$max) has been advocated as an important mediator of effort perception during exercise (Davies & Sargeant, 1979; Dunbar, Goris, Michielli, & Kalinski, 1994; Ekblom & Goldbarg, 1971; Eston, Davies, & Williams, 1987; Robertson et al., 1990). Chen et al. (2002) have revealed moderate-high validity coefficients of $r = 0.57 – 0.90$ for the RPE and % $\dot{V}O_2$max, across varying exercise modes. It has been suggested that relative $\dot{V}O_2$ is associated with stronger central signals of exertion than absolute values (Robertson, 1982). Often when the RPE is related to % $\dot{V}O_2$max, any individual differences observed in the $\dot{V}O_2$ at absolute intensities of exercise cease to exist (Carton & Rhodes., 1985; Mihevic, 1981; Pandolf, Billings, Drolet, Pimental, & Sawka, 1984). This has been seen during conditions of normoxia and hypoxia (Robertson, Gilcher, Metz, et al., 1979a), with pre- and post-red blood cell reinfusion (Robertson et al., 1979a), during one- or two-limb cycle ergometry exercise (Sargeant & Davies, 1973), and when assessing RPE responses of sedentary or active- (Skinner et al., 1969), lean or obese individuals (Skinner et al., 1973). This relationship has also shown not to be moderated by gender (Demello, Cureton, Boineau, & Singh, 1987; Eston et al., 1987, 2006; Noble, Maresh, & Ritchey, 1981; Sidney & Shepard, 1977; Winborn, Meyers, & Mulling, 1988). Conversely, significant differences have been observed at target exercise intensities during treadmill exercise between passive estimation and active production procedures for relative, but not absolute $\dot{V}O_2$ (Glass et al., 1992). A dissociation between the RPE and relative $\dot{V}O_2$ has also been noted across differing physical activities and modes of exercise (Ekblom & Goldbarg, 1971; Eston & Williams, 1988; Grant et al., 1993), and this has also shown to be moderated by fitness level (Boutcher et al., 1989; Demello et al., 1987). In contrast to Robertson et al. (1979a), the RPE has shown to be unrelated to % $\dot{V}O_2max$ with blood reinfusion (Buick, Gledhill, Froese, Spriet, & Meyers, 1980), as well as during high- and low intensity exercise in different ambient temperatures (Toner, Drolet, & Pandolf, 1986).

Several factors likely contribute to the development of effort perception at a given metabolic cost (lactate production, ventilatory hyperpnea, catecholamine elevation). Thus, it is plausible that other, more readily monitored processes may mediate the influence of relative aerobic demand on the perception of exertion during exercise (Mihevic, 1981).

2.5.4. Relationship between RPE and oxygen uptake ($\dot{V}O_2$ & % $\dot{V}O_2max$) in children:

The strength of the relationship between the RPE and $\dot{V}O_2$ has shown to vary in children; often this is dependent upon the specific ratings scale that is utilised. Using the Borg CR-10 scale to estimate exercise effort during treadmill running, Marinov et al. (2008) reported correlations ranging from r = 0.70 – 0.72 between RPE and $\dot{V}O_2$, across two exercise trials. For CALER and PCERT, high correlations (r = 0.82 – 0.94) have been noted for the RPE with $\dot{V}O_2$ (Barkley and Roemmich, 2008; Marinov et al., 2008; Roemmich et al., 2006). However, a more diverse correlational range (r = 0.32 – 0.94) has been reported when either the OMNI-walk/run, OMNI-bike or OMNI-step scales have been employed, across differing exercise modes (Barkley & Roemmich, 2008; Robertson et al., 2000a, 2005b; Roemmich et al., 2006; Utter et al., 2002b). Duncan et al. (1996) provide evidence that the RPE at the ventilatory threshold may be linked to relative- rather than absolute $\dot{V}O_2$. Furthermore, Roberston et al. (2002) have demonstrated no difference between the $\dot{V}O_2$ responses obtained at target RPEs of 2 and 6 between estimation and production cycle ergometry procedures, although specific correlations were not reported in this study.

2.5.5. Relationship between RPE and ventilation ($\dot{V}_E$) or respiratory rate (RR) in adults:

Ventilatory function and discomfort, such as breathlessness and dyspnea, may be the only central signals of exertion that are consciously monitored during exercise (Bakers & Tenney, 1970; Hampson et al., 2001; Pandolf, 1983; Robertson, 1982). During low-moderate intensities of exercise, $\dot{V}_E$ and RR do not appear to be dominant factors influencing the RPE (Allen & Pandolf, 1977; Edwards et al., 1972; Robertson et al., 1982). Whereas, at higher exercise intensities (45 – 75 % $\dot{V}O_2$max), it is feasible that ventilatory drive may act as a predominant mediator of respiratory-metabolic signals of perceived exertion (Cafarelli & Noble, 1976; Glass et al., 1992; Noble & Robertson, 1996; Pandolf, 1983; Robertson, 1982). A number of studies have reported that the RPE corresponding to the ventilatory breakpoint in adults may range from 11 to 14, according to the Borg 6-20 scale (Robertson et al., 2001). This has been shown irrespective of gender (Demello et al., 1987), level of fitness (Boutcher et al., 1989; Demello et al., 1987; Seip, Snead, Pierce, Stein, & Weltman, 1991), and is generally independent of exercise mode (Robertson et al., 2001). Correlation coefficients of *r* = 0.47 - 0.94 have typically been reported for the RPE with $\dot{V}_E$ and RR (Mihevic, 1981; Robertson, 1982), and Chen et al. (2002) suggest that RR may be the best physiological indicator of physical exertion. However, several studies have reported equivocal findings with regards to $\dot{V}_E$ or RR as mediators of exertional perceptions when experimentally perturbed under conditions of hypnosis (Morgan, Raven, Drinkwater, & Horvath, 1973; Morgan, Hirota, Weitz, & Balke, 1976), hypoxia (Cafarelli & Noble, 1976; Maresh et al., 1993; Robertson et al., 1979a, 1986; Young, Cymerman, & Pandolf, 1982), hyperoxia (Pederson & Welch, 1977), induced erythrocythemia (Robertson et al., 1982) or induced alkalosis (Robertson et al., 1986), This has also been seen for the RPE and $\dot{V}_E$ across differing cycling cadence (Stamford & Noble, 1974; Robertson et al., 1979b), or when exercising in cold, neutral or heated environments (Horstman, 1977; Kamon, Pandolf, & Cafarelli, 1974; Noble, Metz, Pandolf, & Cafarelli, 1973; Pandolf et al., 1972).

Ventilation is known to rise according to a positively accelerating function to compensate for metabolic acidosis and bicarbonate buffering of lactic acid (Orenstein, 1993; Rowland, 2005). Moreover, the point of conscious awareness of $\dot{V}_E$ as a central exertional cue has been shown to coincide with an individual’s lactate threshold (Robertson, 1982). Thus, it is difficult to assert whether $\dot{V}_E$ and RR are direct factors, or merely a single aspect of an integration of multiple conscious and unconscious variables that influence the overall perception of exertion (Demello et al., 1987; Mihevic, 1981).

2.5.6. Relationship between RPE and ventilation ($\dot{V}_E$) or respiratory rate (RR) in children:

Limited research suggests a moderate correlation between the RPE and $\dot{V}_E$ in children. When employing the Borg CR-10 scale or PCERT with healthy boys and girls during treadmill exercise, correlations have been reported at r = 0.49 - 0.52 or r = 0.59 - 0.64, respectively (Marinov et al., 2008). However, the predominant focus of RPE research in relation to $\dot{V}_E$ has involved the identification and reliability assessment of the submaximal RPE equating the ventilatory threshold (VT). In this regard, the RPE corresponding to ventilatory breakpoint in children has been shown to be relatively stable (Duncan et al., 1996; Mahon & Marsh, 1992; Mahon, Duncan, Howe, & Corral, 1997; Mahon, Gay, & Stolen, 1998), irrespective of exercise mode (Duncan et al., 1996). For the Borg RPE scale, the submaximal RPE are reported to range from 11 – 14, and for OMNI-walk/run, a corresponding value of 6 has been noted at VT in children aged 8 – 12 years (Robertson et al., 2001). Although the reliability of the RPE at VT is moderately-high (r = 0.78 – 0.87; Mahon & Marsh, 1992; Weymans & Reybrouck, 1989), large inter-individual variability in exertional responses (RPE range 6 – 19) have been observed (Mahon & Marsh, 1992). Ventilatory threshold in children is generally thought to occur at a similar- (Mahon et al., 1997, 1998) or higher percentage of $\dot{V}O_2$max than in adults (Weymans & Reybrouck, 1989). Moreover, RR is typically higher in children than in adults (Bar-Or., 1983). Yet, children have been shown to rate their RPE at VT lower than- (Bar-Or & Ward, 1989; Mahon & Marsh, 1992), similar to- (Mahon et al., 1997), or higher than- (Mahon et al., 1998) that reported by adults, despite working at a comparable % $\dot{V}O_2$max.

2.5.7. Relationship between RPE and blood pH, or blood lactate (BLa) in adults:

Blood acid-base shifts have been proposed to mediate peripheral sensations of exertion during dynamic exercise. Following induced metabolic acidosis by NH_4Cl ingestion, Kostka and Cafarelli (1982) demonstrated that decreases in blood pH intensified the sensations of exertion. Experimental perturbation of blood pH responses through $NaHCO_3$ ingestion similarly resulted in corresponding changes in differentiated RPE during arm- and leg exercise (Robertson et al., 1986). Support for a causal link between blood pH and the intensity of effort perceptions has also been evidenced during a 12-min supine recovery period following four differing treadmill protocols (Robertson et al., 1992). It is noteworthy however that shifts in blood pH only mediate exertional responses at the higher intensities of exercise (i.e., ≥ 80 % $\dot{V}O_2max$), for instance, once the lactate inflection point has been reached (Noble & Robertson, 1996).

Blood lactate has shown to be a critical factor for the perception of exertion during dynamic exercise, regardless of exercise mode (Ekblom & Goldbarg, 1971; Gamberale, 1972; Robertson et al., 1986), intensity (Allen & Pandolf, 1977; Gamberale, 1972), protocol (continuous cf. intermittent; Edwards et al., 1972), environmental condition (Horstman, 1977), gender (Demello et al., 1987) or level of fitness (Demello et al., 1987; Ekblom & Goldbarg, 1971; Morgan & Pollock, 1977). Like blood pH, BLa appears to have the greatest influence on the perception of exertion at the higher intensities of exercise (i.e. above the lactate threshold; ≥ 65 % $\dot{V}O_2max$), whereas its contribution during lower exercise intensities is suggested to be minimal (Mihevic, 1981; Robertson et al., 1986). Yet, when the RPE was assessed across differing intensities of work, at varying cadence, under conditions of hyperoxia, or induced alkalosis during cycle ergometry exercise, several studies have disputed the mediating effect of BLa on the development of effort perception during exercise (Kay & Shephard, 1969; Löllgen, Graham, & Sjogaard, 1980; Pederson & Welch, 1977; Poulos, Doctor, & Westra, 1974; Stamford & Noble, 1974). Nevertheless, although there is some supporting evidence as to the role of BLa in the development of effort perception during dynamic exercise, the mechanism by which this influence might be mediated, at present, remains unidentified (Carton & Rhodes, 1985).

2.5.8. Influence of catecholamines on RPE:

Plasma catecholamine concentration rises as a function of relative (% $\dot{V}O_2max$) exercise intensity (Peronnet & Szabo, 1993), and this response is unaffected by age (Kastello, Sothmann, & Murthy, 1993). As RPE also increases positively with exercise intensity, catecholamines have been proposed as indirect mediators that influence exertional perceptions via normal hormonal regulation of energy metabolism (Noble & Robertson, 1996). Perceived exertion has shown to moderately correlate with circulating levels of epinephrine (r = 0.54) and norepinephrine (r = 0.63; Skrinar, Ingram, & Pandolf, 1983). Notable elevations in catecholamine concentration occur at higher (≥ 70 % $\dot{V}O_2max$; Carton & Rhodes, 1985) but not lower intensities of exercise (Frankenhaeuser, Post, Nordheden, & Sjoeberg, 1969). Accordingly, it is postulated that an intensity threshold exists; after which catecholamine levels exert more potent mediating effects on effort perception. This threshold has been suggested to occur alongside the lactate inflection point, and coincides with a greater reliance on carbohydrate metabolism during high intensity exercise (Noble & Robertson, 1996). Conversely, when hormonal responses have been manipulated via carbohydrate supplementation (Felig, Cherif, Minagawa, & Wahren, 1982), adrenaline infusion (West et al., 2006), or alterations in exercise mode (Coast, Cox, &

Welch, 1986; Horstman, Morgan, Cymermen, & Stokes, 1979), a number of studies have indicated that the perception of exertion is independent of plasma catecholamine levels.

2.5.9. Influence of carbohydrate and caffeine on RPE:

Carbohydrate (CHO) supplementation has been shown to attenuate perceived exertion responses during moderate- and high intensity prolonged work (Backhouse, Bishop, Biddle, & Williams, 2005; Burgess, Robertson, Davis, & Norris, 1991; Utter, Kang, Nieman, & Warren, 1997; Utter et al., 1999, 2007). This response has also been observed with CHO ingestion during high-intensity endurance exercise in the heat (35 ºC; Carter, Jeukendrup, Mundel, & Jones 2003). A reduction in the RPE with CHO ingestion is associated with enhanced CHO oxidation, higher plasma glucose and insulin levels, and lower levels of plasma cortisol (Utter et al 2004a). The mechanism behind this relationship may be attributed to the increased substrate availability of blood-borne glucose for brain / muscle energy metabolism when endogenous CHO stores are depleted (Burgess et al., 1991). Conversely, CHO ingestion has shown no attenuating effects on the RPE during resistance exercise (Utter et al., 2005), time-trial cycling (Beelen et al., 2009), high-intensity intermittent- (de Sousa, Simões, Oshiiwa, Rogero, & Tirapegui, 2007), marathon- (Utter et al., 2002a), or ultramarathon running (Utter et al., 2003), despite several of these studies reporting notable corresponding elevations in exercise performance.

Caffeine ingestion has been shown to attenuate RPE responses and enhance performance during prolonged cycling in a warm environment (Cureton et al., 2007). Hadjicharalambous et al. (2006) have also provided evidence that caffeine may reduce effort perception during constant-load cycling, despite reporting no significant effect on exercise performance. In their meta-analysis, Doherty & Smith (2005) highlight a 5.6 % reduction in the RPE during exercise, in association with overall performance improvements of 11.2 % as a result of caffeine intake. Decreases in effort perception during exercise may be attributed to the direct stimulatory effect of caffeine on the central nervous system (Hadjicharalambous et al., 2006) which, in turn, may partly explain subsequent ergogenic effects of caffeine on performance (Doherty & Smith, 2005). Conversely, caffeine ingestion has been shown to have no significant effect on the RPE during moderate-intensity, or exhaustive cycling exercise (Hogervorst et al., 2008; Ivy et al., 2009). Hogervorst and colleagues (2008) demonstrated that ingestion of a CHO performance bar containing 100 mg of caffeine resulted in significantly longer completion times during a prolonged ride (65 % $\dot{V}O_2max$) and a cycling time trial to exhaustion (75 % $\dot{V}O_2max$) than in either a CHO-only or placebo group. However, no alterations in the RPE or physiological responses (HR; % $\dot{V}O_2max$) were observed across conditions. These collective findings suggest that other neurological and physiological mechanisms may more readily mediate perceptual responses during exercise.

2.5.10. Influence of temperature on RPE:

Inconsistent evidence exists for the relationship between skin- and core body temperature with the perception of exertion. A number of studies suggest that skin temperature may mediate effort perception in both hot and cold environments (Knuttgen, Nadel, Pandolf, & Patton, 1982; Noble, et al., 1973; Pivarnik & Senay, 1986). During arm and leg exercise in cold water, however, no such relationship has been observed (r = 0.10; Toner et al., 1986). Skin temperature responses are influenced by sweat production as well as skin blood flow and volume (Knuttgen et al., 1982). As such, other regulatory processes may mediate exertional responses during exercise in extreme (hot or cold) environments. Several studies negate the influence of core body temperature on the perception of exertion during exercise, demonstrating a limited (r = 0.14 – 0.20) correlation between these two variables (Davies & Sargeant, 1979; Kamon et al., 1974; Pivarnik & Senay, 1986; Toner et al., 1986). More recently however, correlations between core temperature and the RPE have been reported as r = 0.82 – 0.98 during cycling exercise (Crewe, Tucker, & Noakes, 2008; Nybo & Nielsen, 2001; Simmons, Mundel, & Jones, 2008). Corresponding increases in core body temperature and overall RPE have been observed in prepubertal boys when cycling to exhaustion in the heat (Rowland, Garrison, & Pober, 2007). Similarly, reductions in core body temperature and RPE have also been observed during exhaustive cycling in hot and humid conditions following cold-drink ingestion (Lee, Shirreffs, & Maughan, 2008).

In effect, although early research suggests that there is no causal link between the RPE and body temperature; instead supposing that a corresponding rise in these variables with exercise intensity is likely a function of a shared relation with relative metabolic rate (Noble & Robertson, 1996), more latterly the RPE has been proposed as an important variable that is progressively influenced by increases in body temperature (Tucker & Noakes, 2009).

2.6. Factors affecting the RPE:

2.6.1. Influence of Protocol:

In comparison to continuous exercise protocols, intermittent exercise with adults has been associated with a higher perception of exertion in conjunction with an increased demand on many physiological systems ($\dot{V}O_2$, HR $\dot{V}_E$ & BLa levels; Edwards et al., 1972). Nevertheless, higher validity coefficients between the RPE and numerous physiological variables (including $\dot{V}O_2$, %$\dot{V}O_2max$, HR, $\dot{V}_E$ & BLa) have been observed during progressive intermittent exercise compared with progressive continuous exercise (Chen et al., 2002). It is feasible that the specific protocol design may also influence the reliability of effort estimation and / or production. In this regard, Dunbar (1992) reported intramodal differences in RPE between an estimation GXT on a treadmill involving slow speeds and steep gradients, and a subsequent perceptually-regulated exercise bout involving increases in speed only. The authors attributed the observed variations in RPE to the inherent difference in the perception of effort during walking and running.

To date, the majority of research assessing perceived exertion responses or prescribing effort ratings with children has employed a continuous exercise protocol. For example, the CERT and OMNI scales of perceived exertion were devised and validated during continuous exercise. Although a direct comparison between exercise protocols on perceived exertion responses is yet to be conducted, Eston & Parfitt (2007) have provided tentative evidence to suggest that an intermittent (or discontinuous) protocol may be more suitable for use with young children. In their study involving only one 8 year-old boy, perceived exertion responses were higher at a given HR during a continuous treadmill protocol. Moreover, exercise was volitionally terminated at a submaximal intensity (~ 150 $b \cdot min^{-1}$) during the continuous protocol cf. intermittent (~ 190 $b \cdot min^{-1}$), with the boy expressing that the intermittent protocol was ‘preferable’. Lamb, Trask, and Eston (1997) have additionally reported a stronger relationship between RPE (CERT) and HR for an intermittent protocol (r = 0.66) than a continuous protocol (r = 0.46) during perceptually-regulated cycle ergometry, with children aged 9 – 10 years. These preliminary findings are pertinent with regards to the ecological validity of the RPE, given that children’s activity patterns are rarely consistent in nature (Eston, 2009a; Eston & Parfitt, 2007).

2.6.2. Influence of training and level of fitness:

The effect of an individual's level of fitness on the perception of exertion during exercise remains equivocal. During prolonged cycling at a constant load (> 30-mins) or track running, individuals of low-moderate aerobic fitness have been shown to perceive exercise as more strenuous than high-fit athletes, for a given relative workload or running velocity (Garcin, Mille-Hamard, & Billat, 2004; Green, Pritchett, McLester, Crews, & Tucker, 2007). This has also been seen during progressive cycling at 40 – 80 %$\dot{V}O_2$max, or during walking and running at comparable intensities in high- and low-fit men (Berry, Weyrich, Robergs, Krause, & Ingalls, 1989; Travlos & Marisi, 1996). Yet others have reported lower- (Winborn et al., 1988) or comparative RPE responses (Ekblom & Goldbarg, 1971; Parfitt, Eston, & Conolly, 1996; Pivarnik et al., 1993) for low-fit individuals at a given physiological cost. Kaufman, Berg, Noble, and Thomas (2006) noted that self-regulated running at an RPE 13 or 17 elicited statistically greater maximum oxygen uptake reserve values in low-fit, than high-fit men and women. Conversely, Parfitt et al. (1996) reported no difference in % $\dot{V}O_2$max at RPEs 9, 13 & 17 between high- and low-active women.

Submaximal RPE at the lactate threshold or VT is unaffected by training status (Demello et al., 1987; Garcin et al., 2004; Green et al., 2007). In this regard, trained and untrained men and women perceive exercise at the lactate threshold equally as "somewhat hard" (RPE 13 – 14; Demello et al., 1987). When RPE is expressed as a percentage of exercise duration, no effect for fitness level is observed (Garcin et al., 2004). Moreover, level of fitness does not moderate the RPE: $\dot{V}O_2$ relationship during maximal cycle ergometry exercise (Faulkner & Eston, 2007; Faulkner et al., 2007).

2.6.3. Influence of gender:

When effort perception is linearly related to absolute oxygen consumption, women have a tendency to rate their perception of exertion higher than that of men (Demello et al., 1987; Faulkner & Eston, 2007; Garcin, Fleury, Mille-Hamard, & Billat, 2005; Henriksson, Knuttgen, & Bonde-Peterson, 1972; Noble et al., 1981; Pincivero, Coelho, & Campy 2004; Robertson et al., 2000b). Such a variation has been attributed to the differences in aerobic capacity of men and women (Noble et al., 1981). Conversely, exertional ratings of men are higher than women when expressed as a percentage of maximal heart rate reserve (Glass, Whaley, & Wegner, 1991; Whaley, Woodall, Kaminsky, & Emmett, 1997).

Nevertheless, several authors have found no differences in the perception of exertion between men and women when work is expressed relative to their maximal aerobic power (Ekblom & Goldbarg, 1971; Eston et al., 1987; Garcin et al., 2005; Noble et al., 1981; Sidney & Shephard, 1977; Robertson et al., 2000b; Ward et al., 1991). Overall and differentiated RPE do not differ for men and women at the respiratory compensation point during cycle ergometry or treadmill exercise (Green, Crews, Bosak, & Peveler, 2003), at the lactate threshold (Demello et al., 1987), or at a given submaximal BLa level (4 mM; Held & Marti, 1998). Furthermore, gender does not moderate the prediction of $\dot{V}O_2max$ from submaximal RPE (Eston et al., 2006; Faulkner et al., 2007). Gender differences in the RPE are also not apparent during maximal isometric resistance exercise at given submaximal intensities (Pincivero, Coelho, Campy, Salfetnikov, & Bright, 2001; Pincivero, Campy, & Coelho, 2003; Pincivero et al., 2004). Moreover, no difference has been observed in the HR responses of boys and girls during self-regulated running at perceptual intensities of 2, 6 and 10 (OMNI scale), across 3-repeated-trials (Groslambert, Monnier-Benoit, Grange, & Rouillon, 2005). A similar finding has been noted for an intermittent, estimation-production cycling procedure (Robertson et al., 2002).

2.6.4. Cardiorespiratory and peripheral signals of exertion:

As an extension of Borg's (1962) original work, Ekblom & Goldbarg (1971) proposed a two-factor model of RPE that supposes an individual's *overall* perception of exertion is resultant upon the integration of various sensory cues possessing different perceptual weightings. In this model, physiological cues emanating from the peripheral working muscles and joints are classified as 'local' factors, and cardiorespiratory sensations (tachycardia, tachypnea, dyspnea) are referred to as 'central' factors. However, this *gestalt* of perceived exertion restricts the ability to distinguish the discrete exertional symptoms arising from regionalised areas of the body. Thus, a latter modification proposed the development of *differentiated* RPE (Kinsman & Weiser, 1976; Pandolf, Burse, & Goldman, 1975) to concisely identify the dominant exertional signals arising from the periphery (muscle lactate, mechanoreceptor and Golgi tendon activity) or respiratory-metabolic (HR, $\dot{V}O_2$ $\dot{V}_E$, RR) systems during exercise (Green et al., 2003; Noble & Robertson, 1996; Robertson, 1979a). The duration and intensity of an activity have been proposed to mediate the relative contribution of local (*peripheral*) and central (*respiratory-metabolic*) factors on the overall effort sense during dynamic exercise (Robertson, 1982; Ueda, Kurokawa, Kikkawa, Choi, 1993). Moreover, the strength of peripheral or respiratory-metabolic signals of exertion during exercise is resultant upon the extent of limb involvement and the aerobic requirement of the exercise task (Cafarelli, Cain, & Stevens, 1977; Davies & Sargeant, 1974; Dunbar et al., 1992; Ekblom & Goldbarg, 1971; Horstman et al., 1979; Pandolf, 1982; Robertson et al., 1990; Sargeant & Davies, 1977). It is postulated that at the onset of aerobic exercise, sensations of exertion are primarily derived from local signals within the working muscles (Pandolf, 1983). This has been attributed to the greater anaerobic energy contribution during the first 30-s of work (Robertson, 1982). Thereafter, central sensory signals act as amplifiers to potentiate the local cues of exertion relative to the aerobic demand of the exercise task (Cafarelli, 1977; Ekblom & Goldbarg, 1971; Robertson, 1982).

Typically, local sensations of exertion have been shown to dominate the overall effort sense during cycling in adults (Borg & Noble, 1974; Cafarelli et al., 1977; Garcin, Vautier, Vandewalle, Wolff, & Monod, 1998; Green et al., 2003; Hetzler et al., 1991; Koivula & Hassmén, 1998; Pandolf, 1982; Pandolf et al., 1975, 1984) and 10-year old children (Mahon, Plank, & Hipp, 2003). Cycling has been shown to activate a greater proportion of fast twitch fibres than running (Borg, Ljunggren, & Ceci, 1985; Noble et al., 1983; Pandolf et al., 1975), which may in turn stimulate greater afferent input from various peripheral sensory receptors (i.e. pain receptors, muscle spindles and Golgi tendons; Pandolf et al., 1975), and thus result in a relatively greater perception of exertion (Green et al., 2003). During higher power outputs, the magnitude of aches and pains of the legs increase as a consequence of metabolic acidosis and impaired excitation-contraction coupling of skeletal muscle (Borg et al., 1985; Kostka & Cafarelli, 1982; Noble et al., 1983; Pandolf et al., 1984; Robertson et al., 1986). As muscles fatigue, motor unit recruitment and firing frequency are increased, making a constant power output feel progressively harder (Cafarelli, 1977; Kostka & Cafarelli, 1982; Löllgen et al., 1980). Greater local sensations of exertion (muscle pain/knee pain) are also often associated with lower cadence (Coast et al., 1986; Jameson & Ring, 2000; Löllgen, Ulmer, Gross, Wilbert, & von Nieding, 1975; Löllgen, Ulmer, & Nieding, 1977; Robertson et al., 1979b), as a lower cadence necessitates a greater external resistance to be overcome (Cafarelli, 1977). The utilisation of a smaller muscle mass during cycling may also be an associated factor (Berry et al., 1989; Cafarelli et al., 1977; Gamberale, 1972; Pandolf et al., 1984; Skinner et al., 1973). Research has similarly shown that higher cadence may elicit greater exertional ratings (Coast et al., 1986; Hamer, Boutcher, & Boutcher, 2005). This may be attributed to a decreased efficiency in individuals with a higher percentage of slow-twitch muscle fibres (Suzuki, 1979). It is likely that the increased metabolic cost of cycling at a cadence greater or less than optimum will result in a lower gross efficiency, and thus a greater lactate accumulation (Coast et al., 1986). Therefore, the influence of peripheral sensory input on effort perception may only be notable at extreme cadences (i.e. 40 or 120 rev·min^{-1}).

Although local signals have been asserted to dominate the overall perception of exertion across all power outputs (Pandolf, 1983), research has shown that as pulmonary ventilation increases during higher intensities of exercise, respiratory-metabolic signals of exertion become more pronounced (Cafarelli, 1977; Cafarelli et al., 1977; Carton & Rhodes, 1985; Ekblom & Goldbarg, 1971; Jameson & Ring, 2000; Robertson, 1982). As such, central factors appear more significant during treadmill exercise (Kay & Shephard, 1969; Pandolf et al., 1975), and during prolonged cycling at a constant load (Cafarelli, 1977). Essentially, it appears that if one specific cue (local / central) is accentuated over another by elevated rate, concentration or value, it will dominate the overall perception of exertion (Pandolf, 1978, 1982).

2.7. Exercise protocols:

2.7.1. Estimation:

The RPE are often utilised to passively estimate the perception of exertion in relation to physical work. The *estimation* mode requires the exerciser to subjectively evaluate their current level of exertion by assigning a number or an appropriate phrase (according to the ratings scale being employed) to a given exercise intensity (Borg, 1982). Using the estimation procedure, the RPE have shown to be a valid and reliable means to quantify and prescribe training intensity levels (ACSM, 2010; Eston et al., 1987; Mercer, 2001; Robertson et al., 1990), or to predict maximal working capacity (Eston & Thompson, 1997). Indeed, Eston & Thompson (1997) demonstrated the RPE to be a good predictor of maximal work rate in patients receiving ß-blockade therapy. Moreover, the RPE are at least as good as, if not better than HR at predicting exercise intensity (Borg & Linderholm, 1970; Eston et al., 1987; Morgan & Borg, 1976; Noble et al., 1981). During treadmill running, Noble et al. (1981) have reported a 14 % underestimation in the prediction of $\dot{V}O_2max$ using submaximal HR whereas submaximal RPE was shown to predict $\dot{V}O_2max$ to within a +2 % error. These findings mirror those of an earlier study which demonstrated RPE to accurately predict maximal work capacity to within a 1 % of the measured value, whilst submaximal HR overestimated the measured maximal value by 15 % (Morgan & Borg, 1976). In children aged 10 – 14 years, the submaximal RPE reported during a resistance exercise session have also been shown to accurately predict 1-RM using the OMNI-Resistance scale of perceived exertion (Robertson et al., 2008).

2.7.2. Production:

A secondary approach has been to utilise the RPE for the purpose of regulating exercise intensity. In the *production* mode, individuals are prescribed an RPE according to a given perceptual scale to which they have to adjust their force output in order to attain a corresponding intensity of exercise. As such, the regulation of exercise intensity in this manner is often regarded as an *active* process. A number of studies have demonstrated the applicability of the RPE during self-regulated exercise procedures (Dunbar et al., 1992; Eston et al., 1987; Glass et al., 1992; Kang et al., 1998; Marriott & Lamb, 1996; Ward et al., 1995). More recently, this technique has been employed with children with relative success, using both continuous and intermittent exercise procedures (Eston et al., 1994, 2000; Lamb, 1996; Lamb et al., 1997; Robertson et al., 2002; Ward et al., 1991; Williams et al., 1991; Yelling et al., 2002).

In a meta-analysis concerning the employment of the RPE with adults, Chen et al. (2002) reported higher validity coefficients for HR and the RPE during production, rather than the estimation mode. In children aged 7 – 11 years however, three or more production trials have been recommended in order to achieve reliable results during intermittent cycle ergometry or stepping exercise (Eston et al., 2000; Parfitt et al., 2007).

2.7.3. Estimation-Production:

Perhaps the most prevalent use of the RPE for both adults and children is during an estimation-production procedure. An estimation-production paradigm typically comprises the prescription of an RPE during production mode which has been anchored to physiological response (i.e. 70 %HRmax or $\dot{V}O_2$; BLa value) derived from a prior GXT (Williams & Eston, 1989). Several authors attest to this as a valid means of prescribing appropriate exercise intensity with both adults (Dunbar et al., 1992, 1994; Eston & Williams, 1988; Eston et al., 1987; Glass et al., 1992; Kang et al., 1998, 2003; Smutok et al., 1980; van den Burg & Ceci, 1986) and children (Robertson et al., 2002; Ward & Bar-Or, 1990; Ward et al., 1991; Williams et al., 1991). Dunbar (1992) observed a mere 1.6 % mean difference in $\dot{V}O_2$ between an estimation cycle ergometer GXT and subsequent production trials at self-regulated target exercise intensities. Moreover, Kang et al. (1998) demonstrated good reliability in the RPE at exercise intensities equating 50 % and 70 % $\dot{V}O_2$peak between estimation and production procedures using arm-crank ergometry. A comparable finding was noted for leg ergometry at 50 % of $\dot{V}O_2$peak in this study; however participants ‘underproduced’ exercise intensity when guided by the RPE at 70 % $\dot{V}O_2$peak.

Nevertheless, further studies have identified good repeatability in HR (Eston et al., 1987; Groslambert et al., 2005; Gutmann, Squires, Pollock, Foster, & Anholm, 1981; Marriott & Lamb, 1996; Robertson et al., 2002) and $\dot{V}O_2$ (Robertson et al., 2002) between estimation and production exercise procedures, for both adults and children.

It is noteworthy however that a number of investigators have reported a disparity between the exercise intensity associated with a given RPE during estimation and production modes (Byrne & Eston, 1998; Chow & Wilmore, 1984; Dunbar et al., 1994; Eston et al., 2006, 2008; Faulkner et al., 2007; Kang et al., 1998; Marriott & Lamb, 1996; Ward et al., 1995). This may also be referred to as a lack in 'prescription congruence' (Robertson et al., 2002). Often, this manifests as an 'underproduction' in exercise intensity. For example, Dunbar et al. (1994) reported significantly lower corresponding physiological responses ($\dot{V}O_2$ or HR) during repeated bouts of cycle ergometry when compared to target variables elicited from a prior GXT. Yet, there is also some evidence that participants may 'overproduce' exercise intensity during track running and rowing ergometry (Ceci & Hassmén, 1991; Marriott & Lamb, 1996). Ward et al. (1991) demonstrated that the prescription of exercise during track walking/running elicited significantly different intensities to those initially reported during a cycling estimation trial. Robertson et al. (1990) have suggested however that cross-modal exercise prescription using perceptual estimation is physiologically valid when exercise intensity is prescribed according to relative rather than absolute $\dot{V}O_2$. Improvements in the accuracy of self-regulating exercise have been shown at the higher exercise intensities (i.e. above RPE 15; Marriott & Lamb, 1996). This finding has been noted elsewhere for intramodal exercise tasks (Eston et al., 1987; Smutok et al., 1980). Conversely, Dunbar (1992) reported that the reliability of intramodal regulation of exercise was reduced at the higher exercise intensities when guided by the RPE.

Discrepancies in the corresponding physiological responses at equivalent RPE during estimation and production procedures are likely attributed to the differences in the psychophysical processes involved in each task. Noble (1982) suggests that ‘actively’ reproducing exercise from memory is entirely unlike ‘passively’ assessing the intensity of effort when the exercise task is ongoing. The disparity between these two processes may appear greater in children than adults, likely resultant upon a child’s relatively limited perceptual experience (Lamb et al., 2008). Consequently, Byrne & Eston (1998) recommend caution when using RPE responses obtained during an estimation GXT for the purpose of RPE production. Nevertheless, an estimation-production procedure is generally supported as an appropriate means to prescribe a wide range of exercise intensities to individuals who vary in age, fitness, or clinical status (Noble & Robertson, 1996).

2.7.4. Novel application of the estimation-production procedure:

An alternative and novel application of the estimation-production paradigm was recently suggested and empirically tested by Eston et al. (2005, 2006, 2008). On the proviso that such an application would facilitate acceptably accurate predictions of $\dot{V}O_2max$, a GXT comprising a series of progressive, submaximal effort production levels was proposed as a suitable means to prescribe exercise intensity. In the seminal study by Eston et al. (2005), ten physically active male participants performed a discontinuous exercise test on a cycle ergometer at five incremental, self-regulated intensities equating to 9, 11, 13, 15 & 17, according to the Borg 6-20 RPE scale, on three separate occasions. Increments in work rate were of 4-min duration and each was separated by a 4-min active recovery period, cycling at 40 W. Linear extrapolation of the submaximal RPE in relation to the observed $\dot{V}O_2$ response (see Figure 2.9) revealed estimates of $\dot{V}O_2max$ to be more accurate when extrapolated from a higher perceptual range (i.e. when RPE 17 was included in the analysis). Practice also appeared to improve the repeatability of predictions, as demonstrated by the typically higher intraclass correlation coefficients (ICC) and narrower 95 % limits of agreement (LoA) reported between the second and third production trials.

A second study has investigated the influence of protocol duration on the validity of $\dot{V}O_2max$ predictions of both men and women during continuous, perceptually-regulated exercise (Eston et al., 2006). Five self-regulated exercise intensities were again employed; yet in this study, increments were either of 2-min or 4-min duration. The authors similarly noted acceptable estimates of $\dot{V}O_2max$ from each of the perceptual ranges employed, particularly from the protocol of 2-min duration, which were not moderated by gender.

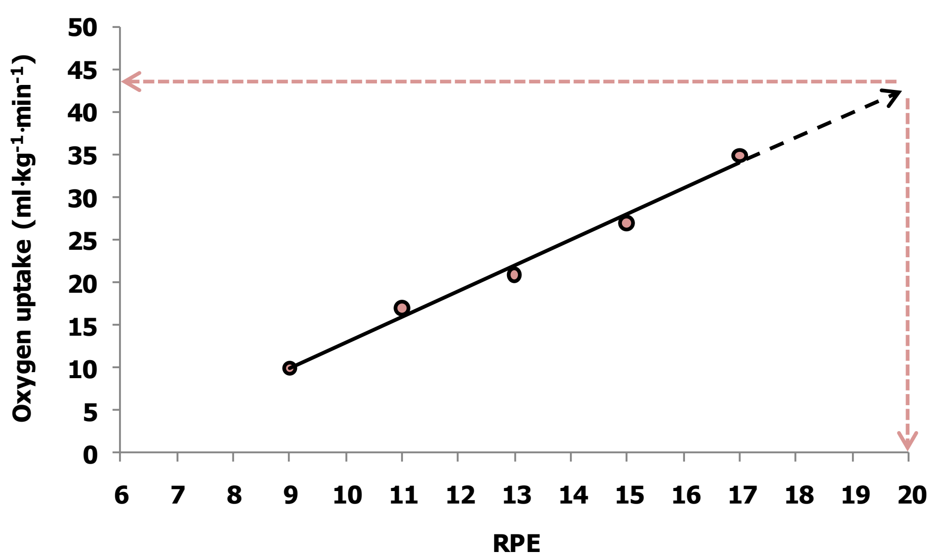

Figure 2.9. Linear regression analysis plot demonstrating a prediction of $\dot{V}O_2max$ from an RPE 17 (RPE 9-17) when extrapolated to the theoretical maximal RPE (20).

A further study utilising this approach (Eston et al., 2008) aimed to identify its applicability with healthy adult males of low-fitness. Employing a near identical study design to that of Eston et al. (2005), accurate predictions of $\dot{V}O_2max$ were obtained from the submaximal RPE ranges that incorporated the RPE 17 (9-17, 11-17), however, predictions from the RPE range 9-15 significantly underestimated measured $\dot{V}O_2max$. Repeatability was also shown to be lower in this population than in the previous studies involving active individuals. The authors attributed this finding to the comparatively limited experience of sedentary individuals at interpreting cardiorespiratory, thermal and metabolic cues of exertion, coupled with the unfamiliarity of controlling pace during moderate to vigorous exercise. In contrast, a study by Faulkner et al. (2007) has demonstrated that accurate predictions of $\dot{V}O_2max$, which are not moderated by gender or activity status, may be obtained when submaximal RPE are extrapolated from a lower perceptual range (9-13, 9-15). However, predictions of $\dot{V}O_2max$ in this study were once again shown to be more accurate from the third production trial, with the sedentary group demonstrating the greatest variability in work rate across trials one – three, further supporting the postulation that sedentary individuals lack the necessary exercise experience to reliably regulate their exercise intensity. A more recent study by Morris, Lamb, Cotterrell, & Buckley (2009) corroborates the findings of Faulkner et al. (2007), when using a randomised perceptually-regulated exercise procedure of either 2- or 3-min duration. In addition to the utility of perceptually-regulated protocols, accurate predictions of $\dot{V}O_2max$ have been obtained from the RPE estimated during a GXT. Faulkner and Eston (2007) revealed $\dot{V}O_2max$ predictions that were not dissimilar to measured $\dot{V}O_2max$ when extrapolated from an RPE 13, 15 or 17, for high- and low-fit men and women. Similarly, Coquart et al. (2009b) have demonstrated that accurate estimates of $\dot{V}O_2max$ may be obtained from a single estimation test to an RPE 13 in a population of healthy, obese women. Davies, Rowlands, and Eston (2008) have also demonstrated that the RPE provided during the multistage fitness test (MFT) or during a laboratory-based simulated MFT on a treadmill, may both afford accurate estimates of $\dot{V}O_2max$ when extrapolated from RPE ranges 7-17, 9-17, 11-17 and 9-15.

Recently, a similar application of the RPE to that employed in the aforementioned studies has been observed for the regulation of intensity during resistance exercise. Lagally and Amorose (2007) demonstrated that the weights lifted when participants were requested to produce an intensity equating an RPE of 9, 13 and 17 closely corresponded to that lifted during a previous estimation trial for the same perceived effort levels. Furthermore, Eston and Evans (2009) have demonstrated that extrapolation of the submaximal RPE equating to 20 – 60 % of an individual's 1-repetition maximum (1RM), during either a bicep curl or a bilateral knee-extension, can predict 1-RM with relative accuracy. A recent study by Robertson et al. (2008) has utilised the submaximal RPE derived from biceps curl and knee extension exercises to develop sex-specific regression equations in order to predict 1-RM with children, yet further research using these techniques are scarce with children.

2.8. Repeatability of the RPE:

Several studies have examined the effects of protocol familiarisation on the perception of effort during an estimation-production paradigm, and the extent to which practice may influence the estimates of maximum physiological cost during exercise. Following a GXT to establish the relationship between RPE and HR with treadmill speed, Smutok et al. (1980) demonstrated that participants could reproduce equivalent speeds with acceptable accuracy across two further trials when guided by the RPE. In this regard, a high repeatability in the RPE was established, with correlations of $r = 0.83 – 0.85$ evidenced for the RPE with treadmill speed. However, when the RPE were regressed against HR, notable statistical differences in exercise responses were observed at the lower exercise intensities

(HR < 150 b·min^{-1} or < RPE 12), across trials. Thus, the authors concluded that such a procedure has potentially dangerous implications if employed with a cardiac population. Conversely, during an 8-week training programme wherein post-operative cardiac patients worked at self-selected exercise intensities, Gutmann et al. (1981) reported that estimates of effort for a given HR response repeatedly approximated those obtained during an initial stress test for an equivalent physiological cost. In healthy adults, between trial reliability has been shown to improve with familiarisation and the employment of various anchoring techniques when utilising the RPE (Eston & Williams, 1988; Eston et al., 2005, 2006, 2008), particularly at higher levels of exertion (Eston et al., 1987; Smutok et al., 1980). Similar observations have been noted when using a Braille version of the RPE scale (Buckley et al., 2000), and several paediatric ratings scales, including the CALER and BABE (Eston et al., 2000; Parfitt et al., 2007). Conversely, owing largely to the use of arguably better statistical techniques, Hartshorn and Lamb (2004) demonstrated no significant improvements in test-retest reliability across four perceptually-regulated cycle trials; suggesting that the RPE scale may possess limited practical utility for the regulation or prescription of exercise. This finding supports the earlier research of Lamb, Eston, and Corns (1999) that questioned the reliability of the RPE during treadmill running across two-repeat estimation GXTs.

2.9. Perceived exertion and the regulation of performance:

2.9.1. Exercise-induced fatigue:

Several physiological models have been proposed to limit exercise capacity (for review see Noakes, 2000), but to date, no single variable has adequately explained exercise-induced fatigue. Fatigue may be defined as an inability to maintain the required or expected power output (Fitts, 1994), in association with an increased perception of effort (Enoka &

Stuart, 1992). The underlying mechanisms associated with fatigue may been generalised into two main categories: peripheral fatigue and central fatigue. Peripheral fatigue signifies a failure in skeletal muscle contractile function that is independent of reduced muscle activation by the central nervous system (CNS; Noakes & St Clair Gibson, 2004). Peripheral sensations of fatigue are located distal to the point of nerve stimulation and have been attributed to a number of factors, including muscle metabolite accumulation (Fitts, 1994), substrate depletion (Coggan & Coyle, 1987; Coyle, Coggan, Hemmert, & Ivy, 1986; Tsintzas, Williams, Boobis, & Greenhaff, 1996), mechanoreceptor activity (Mihevic, 1981; Noble et al., 1973), disturbances in excitation-contraction coupling (Allman & Rice, 2002; Delbono, Renganathan, & Messi, 1997; Westerblad, Bruton, Allen, & Lannergren, 2000), and cardiovascular and respiratory limitations (Bassett & Howley, 1997; Howley, Bassett, & Welch, 1995). This peripheral model suggests that fatigue is a negative and unavoidable consequence of physical activity (Kirkendall, 1990). However a number of studies refute the peripheral model. Homeostatic disturbances within skeletal muscle have not been shown to cause fatigue during static or dynamic exercise (in vivo) in the presence of an intact CNS (Fitts, 1994; Noakes, 2000; Spriet, Soderland, Bergstrom, & Hultman, 1987; St Clair Gibson & Noakes, 2004). In fact, Noakes (2000) has asserted that total substrate (ATP) depletion is implausible on the basis that if rate of ATP use exceeded production, the outcome would be skeletal muscle rigor and ultimately cell death, not fatigue. Furthermore, participants have been shown to terminate exercise despite adequate carbohydrate stores and oxidation rates (Fitts, 1994; Rauch, St Clair Gibson, Lambert, & Noakes, 2005).

More recently, it has been suggested that the CNS is the limiting factor affecting exercise performance (Gandevia, 1998; Nybo & Nielsen, 2001; St Clair Gibson & Noakes, 2004). In this regard, central fatigue (originating in the CNS), may be defined as a progressive failure in the level of voluntary muscle activation (Allman & Rice, 2002), which may be mediated by intrinsic motoneuronal, spinal, or supraspinal factors (Gandevia, 2001), independent of changes in skeletal muscle contractility (Enoka & Stuart, 1992). Accordingly, several complex control systems involving the brain have been proposed to limit/control motor functioning or optimise exercise performance (Atkinson, Peacock, St Clair Gibson, & Tucker, 2007; Lambert, St Clair Gibson, & Noakes, 2005).

2.9.2. Teleoanticipation:

In a process described as *teleoanticipation* (Ulmer, 1996), it is postulated that the brain regulates exercise performance through central calculations that attempt to couple the metabolic and biomechanical limits of the body to the demands of the exercise task (Hampson et al., 2001). This model suggests that prior to the onset of exercise the brain predetermines the initial power output (overall pacing strategy) that is required for an exercise bout in a feedforward manner, based upon the known distance or duration of the event. Ulmer (1996) further proposed that through a complex system of efferent (feedforward) and afferent (feedback) commands, the brain acts to ensure that the adopted power output is appropriate in the context of the exercise bout so as to preserve whole body homeostasis whilst concurrently reducing the risk of premature fatigue. Efferent signals contain information on motion, force output, time, and muscular metabolism (Lambert et al., 2005), whilst afferent feedback control mechanisms integrate multiple signals arising from various peripheral physiological systems and receptors, including metaboreceptors, nociceptors, thermoreceptors, cardiovascular pressure receptors and mechanoreceptors, so as to modify force output and thus optimise performance (Lambert et al., 2005; St Clair Gibson et al., 2006). Moreover, this theory implies that the perception of effort during exercise may be a predominantly feedforward system, using efferent command signals from skeletal muscles to regulate the spatial and temporal pattern of motion, and to control metabolic rate by the adjustment of power output; a process refined through afferent feedback stemming from various regions of the body (Hampson et al., 2001, 2004; Ulmer, 1996). Fundamentally, this premise holds that power output and metabolic rate scale with time; they are set according to how much of the exercise bout has been performed, or how much of the exercise bout remains.

Provisionally, a ‘central programmer’ or ‘black box’ has been suggested to coordinate this regulatory system at a subconscious level (Hampson et al., 2001; Ulmer, 1996). More recently however an extension to the teleoanticipatory theory has been proposed and this has been termed the ‘central governor’ model (St Clair Gibson & Noakes, 2004).

2.9.3. Central Governor Model:

The central governor model posits that the brain regulates power output (pacing strategy) throughout an event by modulating motor unit recruitment, based upon anticipated task duration, to ensure that an exercise task is completed successfully, within the body’s biomechanical and metabolic limits, whilst avoiding catastrophic physiological failure (St Clair Gibson & Noakes, 2004; Ulmer, 1996). This regulatory process may be further refined via subconscious calculations that integrate current metabolic demand with the individual’s level of metabolic fuel reserve, their experience in completing fatiguing tasks, the external environmental conditions, and the knowledge of an endpoint (Mauger et al., 2009a; Rauch et al., 2005; St Clair Gibson & Noakes, 2004; St Clair Gibson et al., 2006; Tucker, 2009). Within this model, fatigue is described as a conscious sensation rather than a physiological occurrence (Ament & Verkerke, 2009; St Clair Gibson et al., 2003).

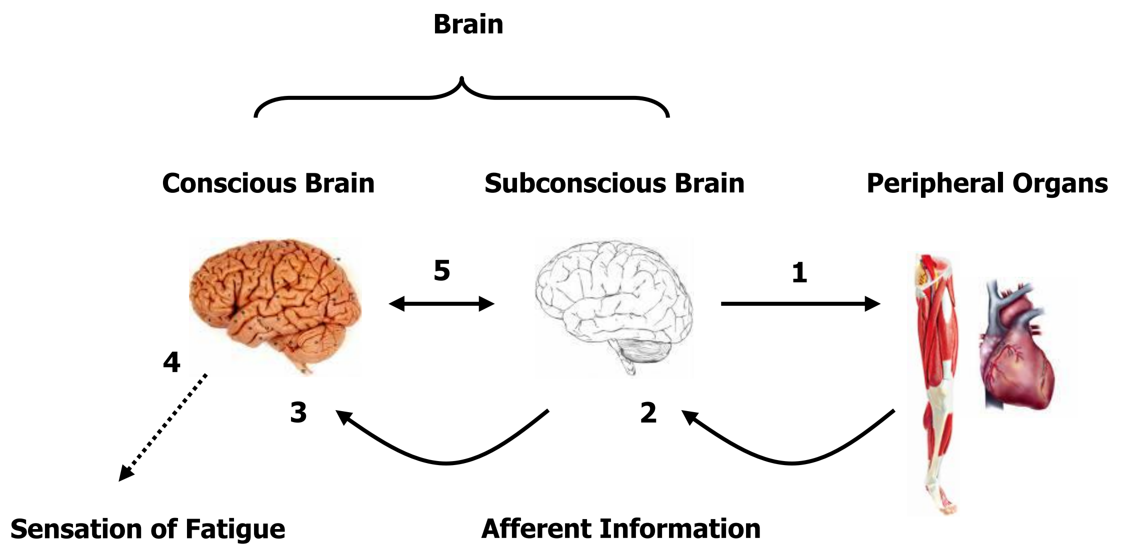

Figure 2.10. The central integrative (central governor) model of exercise regulation. *Note.* Modified from St Clair Gibson & Noakes (2004). Evidence for complex system integration and dynamic neural regulation of skeletal muscle recruitment during exercise in humans. *British Journal of Sports Medicine*, 38, 797-806.

This model suggests that at the onset of exercise, the subconscious brain sets the exercise intensity by determining the number of motor units to be recruited throughout an exercise task [Figure 2.10 – point 1]. Afferent feedback from numerous peripheral organs and sensory receptors, including skeletal and respiratory muscles, the cardiovascular system, chemoreceptors and mechanoreceptors, among others, may influence the extent of skeletal muscle motor unit recruitment [2]. The conscious brain is informed of increases in neural effort associated with a given power output [3], and this is interpreted as an increased sensation of fatigue [4] which may in turn influence further subconscious brain control processes [5] (St Clair Gibson & Noakes, 2004). A pacing strategy therefore alters during exercise as part of an oscillating system for maintaining homeostatic control of the peripheral physiological conditions (Lambert et al., 2005).

2.9.4. Pacing strategies:

During an athletic event wherein the objective is to complete a given distance in the fastest possible time, whilst maintaining enough of a metabolic reserve to avoid premature fatigue, an athlete must employ some form of pacing strategy (St Clair Gibson et al., 2006). A pacing strategy denotes the change in speed throughout an event via the regulation of the rate of energy expenditure (Hettinga, de Koning, Broersen, Van Geffen, & Foster, 2006). Four broad types of pacing strategy have been proposed; these are ‘all-out’, ‘slow start’, ‘even pace’, and ‘variable’ (Figure 2.11; Foster et al., 1994; St Clair Gibson et al., 2006). Using an ‘all-out’ strategy, an athlete will begin an event at their maximal pace and attempt to maintain this pace for the duration of the event; although a decrement in pace may occur near the end. With a ‘slow start’ strategy, an athlete will start at a submaximal intensity and their pace will be continually increased throughout the event. If an athlete employs an ‘even pace’ strategy, they will maintain a constant submaximal pace throughout an event. Alternatively, a ‘variable’ pacing strategy may be employed whereby an athlete will begin an event at maximal pace, their pace will be moderated throughout the middle stage, and then increased near the end of the event.

A pacing strategy may be influenced by internal cues arising from numerous physiological systems during exercise (Albertus et al., 2005; Nikolopoulos, Arkinstall, & Hawley, 2001; Tucker, 2009). Furthermore, the adopted pacing strategy may be largely dependent upon various external cues such as the environment (gradient, terrain, weather), race situation (distance, duration, mode), or degree of competition, in addition to the athlete’s experience and level of motivation (Foster et al., 1994; St Clair Gibson et al., 2006; Tucker & Noakes, 2009).

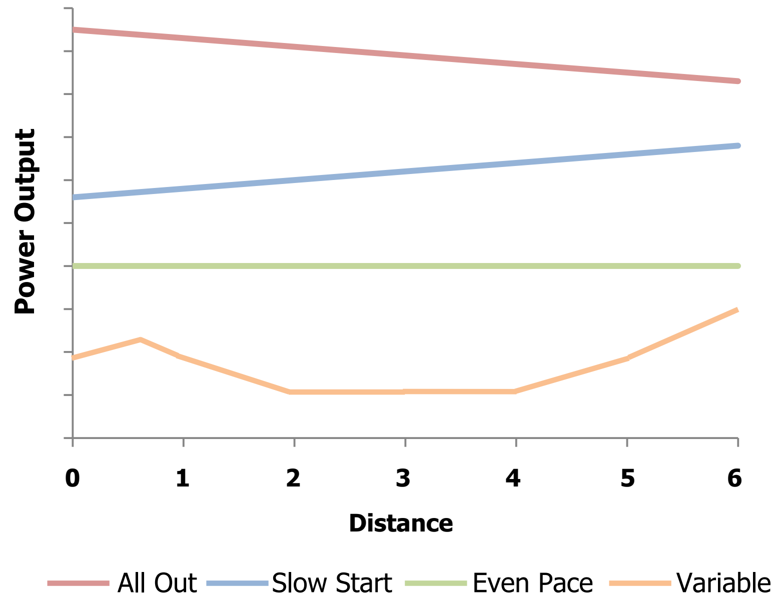

Figure 2.11. Common types of pacing strategy. *Note*. Modified from St Clair Gibson et al. (2006). The role of information processing between the brain and peripheral physiological systems in pacing and perception of effort. *Sports Medicine*, 36, 705-722.

Recent developments of the teleoanticipation and central governor models of fatigue suggest that *pacing schemas*, that are created from prior bouts of analogous exercise and stored for reference in the long-term memory, may impact upon a current pacing strategy (Tucker, 2009). In accord, it is proposed that an *internal clock*, that uses scalar rather than absolute time scales, exists to monitor distance covered and the corresponding time taken to complete a specific exercise bout at a specific pace, in order to refine changes in power output (St Clair Gibson et al., 2006). This scaling mechanism operates on a subconscious level, utilising the memories of prior exercise bouts to interpret current progress in the context of the overall pacing strategy (Albertus et al., 2005; Paterson & Marino, 2004). Importantly, the RPE have been proposed as a mediating factor in this anticipatory model, on the basis that exercise will terminate when the RPE reaches a level which is intolerable or uncomfortable for an athlete (Tucker, 2009). In this regard, it is suggested that the conscious perception of exertion is compared to an *expected* level of exertion at any given stage during exercise to ensure that the conscious RPE does not exceed *acceptable* limits.

2.9.5. Influence of Feedback:

A number of recent studies have examined the influence of feedback on pacing strategies, perceived exertion and overall exercise performance. These studies have typically employed either accurate, inaccurate, or no feedback with regards to time, intensity or duration, during cycle ergometry and running (Albertus et al., 2005; Ansley, Robson, St Clair Gibson, & Noakes, 2004a; Baden, McLean, Tucker, Noakes, & St Clair Gibson, 2005; Faulkner, Parfitt & Eston, 2008; Hampson et al., 2004; Mauger et al., 2009a,b). Albertus and colleagues (2005) investigated whether providing inaccurate distance feedback altered the adopted pacing strategy as well as physiological (HR) and perceptual (RPE) responses of well-trained cyclists, during 20 km time-trials. For the inaccurate feedback trials, participants were advised that they had completed 1 km when in fact they had either cycled anywhere between 25 – 250 m greater or less-than the informed distance. As completion times, pacing strategies and power output profiles between trials were not different, the authors concluded that external distance feedback does not affect exercise performance. If the distance or duration of an exercise bout is known, however, the provision of incorrect feedback is supposed to have little effect on exercise performance, so long as the extent of deception is sufficiently small so as to remain consciously undetected by the individual (Tucker & Noakes, 2009). More recently, Micklewright, Papadopoulou, Swart, and Noakes, (2009) suggest that pacing strategies may be dependent upon an interaction between external feedback and prior experience, rather than being influenced by just one factor.

In the aforementioned study by Albertus et al. (2005), the RPE was shown to be disassociated from work rate across all trials. This led the authors to speculate that at the onset of exercise, RPE is set in a feedforward manner and that power output is regulated throughout a trial specifically to ensure that the RPE rises as a linear function of exercise duration. Similar findings have been noted elsewhere (Ansley et al., 2004a; Crewe et al., 2008; Joseph et al., 2008). A recent study by Mauger et al. (2009a) has examined whether athletes can adopt a successful pacing strategy in the absence of distance feedback. In their study, a control (CON) and experimental (EXP) group of cyclists completed four 4 km time-trials either with or without distance feedback, respectively. A significant difference in completion time was observed between the two groups during the first time-trial, however by the fourth time-trial, the experimental group had developed a similar pacing strategy to the control group, with a mere 2-s difference noted in their completion times (Figure 2.12).

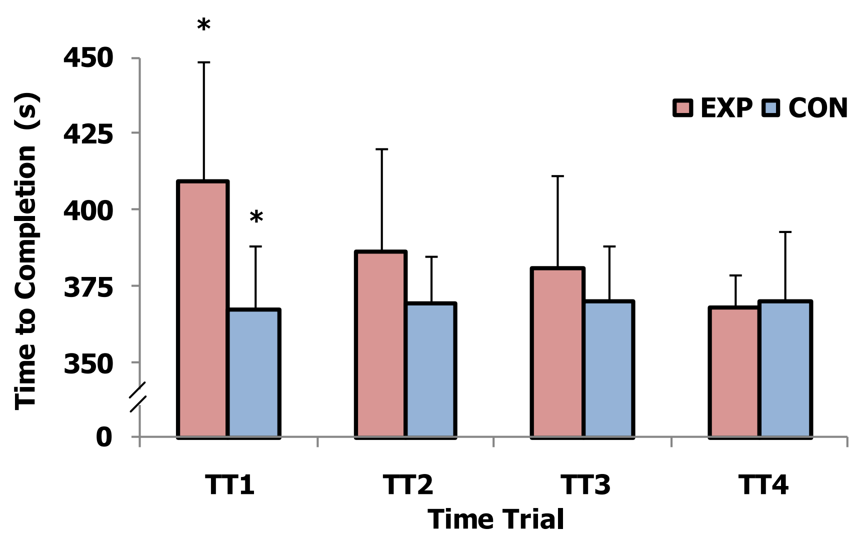

Figure 2.12. Time-trial (TT) completion times for two groups; experimental and control. *Note*. Modified from Mauger et al. (2009a). Influence of feedback and prior experience on pacing during a 4-km cycle time trial, p.453.

* Significantly different (*P* = 0.03) time-trial completion times between groups.

The authors suggested that athletes can adopt an appropriate pacing strategy on the basis of prior experience alone. Moreover, they postulate that pacing, and thus regulation of power output may have been partially influenced by RPE, particularly in the absence of external feedback. These findings highlight the importance of task familiarisation on improving the consistency of RPE (Eston & Williams, 1988; Eston et al., 2005, 2006, 2008), which in turn improves the overall pacing strategy adopted and thus optimises exercise performance (Ansley et al., 2004a; Ansley, Schabort, St Clair Gibson, Lambert, & Noakes, 2004b; Mauger et al., 2009b; Micklewright et al., 2009; St Clair Gibson et al., 2006; Tucker, 2009; Tucker & Noakes, 2009).

2.10. Thesis Rationale:

It is evident that a number of physiological variables, the most commonly considered being $\dot{V}O_2$, HR and $\dot{V}_E$, complement perceived exertion during exercise. To what extent these variables mediate the perceptual response remains unclear. What *is* clear however is that the strength of these relationships provide a medium to predict an individual's maximal functional capacity ($\dot{V}O_2max$) with relative success (Davies et al., 2008; Dunbar & Bursztyn, 1996; Eston & Thompson, 1997; Eston et al., 2005, 2006, 2008, Faulkner et al., 2007; Okura & Tanaka, 2001), as well as aiding the prescription of exercise intensity to healthy populations (Dunbar et al., 1994; Eston et al., 2005, 2006; Kang et al., 2003) and some clinical groups (Eston & Connolly, 1996; Buckley et al., 2000; Levinger, Bronks, Cody, Linton, & Davie, 2004). Indeed the application of the RPE in exercise testing and prescription are recommended by the ACSM (2010). But we must consider the accuracy, or reproducibility of a predicted $\dot{V}O_2max$ value, or perceptually-regulated exercise intensity, particularly when considering the application of such procedures with populations whom may be deemed ‘at risk’ of high intensity exercise, such as sedentary or clinical groups. For these individuals, it would be beneficial to employ shorter duration tests, of a lower intensity, to avoid any potential adverse health implications. As such, studies 1 and 2 of this thesis focussed on various methodological aspects, including employing a single test (no familiarisation), lower intensities, and differing exercise test protocols (GXT cf. ramp-protocol), that may impact upon the accuracy of predicting $\dot{V}O_2max$ from submaximal RPE in sedentary men and women. These studies balance prior knowledge on the influence of repeated-bouts in improving the consistency of $\dot{V}O_2max$ predictions with the desire for reducing test duration, and thus the associated motivational effort required by the exerciser.

What is also evident from the literature is that RPE is a cognitive function reflecting a prolonged and progressive developmental process from childhood to adulthood, and which is far from being fully comprehended. As such, studies 3 and 4 of this thesis consider new approaches to assessing the RPE of young children, employing novel methods and challenging current understanding of the nature of a child’s perceptual response to dynamic exercise. In considering the wealth of literature recently published on the utility of the RPE in predicting $\dot{V}O_2max$ in adults, it was of interest to assess whether such procedures could be employed with accuracy, if at all, with young children. Thus, a further study (study 5) investigated the reliability of submaximal RPE, across differing exercise modes, in predicting the $\dot{V}O_2max$ of young children.

With the knowledge gained in the process of completing these aforementioned studies, and in relation to the recent research with adults into the theoretical constructs of teloanticipation and the central governor models of fatigue, a final study was conducted using a paediatric population. The sixth study of this thesis investigated whether young children adopt pacing strategies during running, and how these relate to their perceptual (RPE) and physiological responses, either with or without a competitive element. This study is pertinent in consideration of the sparse number of investigations into the use of the RPE in field tests, in addition to it being (to the best of my knowledge) the first study of its kind with young children.

Chapter 3

Study 1

Prediction of maximal oxygen uptake from the Åstrand-Ryhming nomogram and ratings of perceived exertion.

This study has contributed to the following publications and presentation:

Publications:

Faulkner, J., Lambrick, D., Parfitt, G., Rowlands, A., & Eston, R. (2009). Prediction of maximal oxygen uptake from the Åstrand-Ryhming nomogram and ratings of perceived exertion. In. T. Reilly, & G. Atkinson (Eds.), *Contemporary Sport, Leisure and Ergonomics*, (pp. 197-214). London: Routledge.

Faulkner, J., Lambrick, D., Parfitt, G., Rowlands, A., & Eston, R. (2009). Comparison of the accuracy of predicting maximal oxygen uptake from the Åstrand-Ryhming nomogram and ratings of perceived exertion. *Journal of Sports Sciences*, 27 (S1), S13-14.

Poster presentation:

Lambrick, D., Faulkner, J., Parfitt, G., Rowlands, A., & Eston, R. Comparison of the accuracy of predicting maximal oxygen uptake from the Åstrand-Ryhming nomogram and ratings of perceived exertion. The 12th Annual Congress of the European College of Sport Science (Jyväskylä, Finland, 13th July, 2007).

3.1 Abstract:

This study compared the measured maximal oxygen uptake ($\dot{V}O_2$max) of twenty-four men and women of low-fitness with predictions of $\dot{V}O_2$max from four submaximal exercise protocols, during cycle ergometry. Each participant performed a graded exercise test (GXT) to volitional exhaustion (measured $\dot{V}O_2$max) with the ratings of perceived exertion (RPE) reported throughout (estimation protocol), an RPE production protocol (RPE 9, 11 & 13) and an Åstrand-Ryhming (Å-R) test (incorporating the Keele-Lifestyle nomogram), in a randomised order. Oxygen uptake ($\dot{V}O_2$), corresponding to RPE values prior to- and including an RPE 13 (estimation & production protocols), were extrapolated to theoretical maximal (20), and peak RPE (19) to predict $\dot{V}O_2$max. There was no significant difference (P > .05) between measured- and predicted $\dot{V}O_2$max for men or women. This study provides further evidence of the utility of submaximal RPE in providing accurate estimates of $\dot{V}O_2$max in low-fit individuals.

3.2 Introduction:

Maximal oxygen uptake ($\dot{V}O_2$max) is the most appropriate indicator of cardiovascular fitness and is often directly assessed during a graded exercise test (GXT). However, due to the practical concerns of conducting exhaustive exercise tests with non-athletic or patient populations, a number of submaximal test protocols have been developed. These include the Åstrand-Ryhming (Å-R) nomogram (Åstrand & Ryhming, 1954), the Young Men's Christian Association (YMCA) cycle test (Golding, Myers, & Sinning, 1982), and the Rockport Fitness Walking Test (Kline et al., 1987), among others. Submaximal exercise tests provide a safe and practical means of assessing aerobic fitness for individuals who are likely to be limited by pain and fatigue, abnormal gait, or impaired balance (Noonan & Dean, 2000).

3.2.1 The Åstrand-Ryhming (Å-R) nomogram:

Developed over 50 years ago, the Å-R nomogram is routinely employed in the assessment of aerobic fitness in large population groups (Dyrstad, Aandstad, & Hallén, 2005; Naidoo & Coopoo, 2007; Thorsen et al., 2005). It is perhaps the most widely adopted method for predicting $\dot{V}O_2$max given the simplicity of its procedure and the minimal time requirements for its employment (Wagganer et al., 2003). Although the ACSM (2010) suggests that the Å-R nomogram may be applied to both conditioned and unconditioned individuals, the nomogram was originally devised using only physically active participants (Åstrand, 1960). This may in part explain the much larger differences reported between measured- and predicted $\dot{V}O_2$max when the Å-R nomogram is employed with untrained individuals. For example, Rowell, Taylor, and Wang (1964) observed that $\dot{V}O_2$max was underestimated by 5.6 ± 4.2 % in highly-trained men, and 26.8 ± 7.2 % in untrained men. The Å-R nomogram has also been shown to overestimate the $\dot{V}O_2$max of African-American men (Vehrs & Fellingham, 2006), and healthy physically active women (Zwiren, Freedson, Ward, Wilke, & Rippe, 1991).

3.2.2 The Keele-Lifestyle RPE nomogram:

Researchers have recently utilised the Borg (1998) 6-20 Ratings of Perceived Exertion (RPE) scale as a means of predicting $\dot{V}O_2$max from submaximal sensations of exertion. The Keele-Lifestyle RPE nomogram (Buckley, Cannon, & Mapp, 1998) was devised to be administered during an Å-R cycle ergometer test to provide a prediction of $\dot{V}O_2$max using the submaximal RPE at a given work rate (WR). Initial investigative efforts revealed the RPE nomogram to significantly underestimate measured $\dot{V}O_2$max (-

0.308 ± 0.407 $L \cdot min^{-1}$) in a mixed group of sedentary, recreational and highly-trained men and women (n = 21, 18 – 43 years), despite a high correlation being observed between measured- and predicted values (*r* = 0.91; Buckley et al., 1998). Thus, a subsequent regression equation was devised to enable more accurate predictions of $\dot{V}O_2$max ($\dot{V}O_2$max = 1.076 (RPE) + 0.085). Yet since its development, no further studies have assessed the validity of the RPE nomogram in estimating $\dot{V}O_2$max in men and women.

3.2.3 Previous applications of estimation and perceptually-regulated exercise protocols:

As discussed in the review of literature, accurate predictions of $\dot{V}O_2$max have been demonstrated when submaximal $\dot{V}O_2$ values have been extrapolated against RPE during passive estimation procedures (Faulkner & Eston, 2007). Recent research has also shown that submaximal, perceptually-regulated graded exercise tests (production protocol), using RPE 9, 11, 13, 15 and 17, provide accurate estimates of $\dot{V}O_2$max in high and low-fit men and women (Eston et al. 2005, 2006, 2008; Faulkner et al., 2007). Interestingly, Faulkner et al. (2007) observed that $\dot{V}O_2$max was predicted with acceptable error when $\dot{V}O_2$ values from the perceptually-regulated RPE range 9-13 were extrapolated to the theoretical maximal RPE 20.

Previous research by Eston and colleagues has assessed the efficacy of active production and passive estimation exercise tests which have been prescribed to a high intensity (i.e. RPE 17), and have followed a period of habituation. With sedentary and certain patient populations of low fitness, it would be of particular benefit if low intensities of exercise (i.e. RPE 9-13) could be used as a suitable predictor of $\dot{V}O_2$max. A lower perceptual range would reduce the potential cardiovascular risk associated with the high intensity exercise (i.e. RPE 17) in sedentary and patient populations of low fitness. With regards to the duration, costs and level of participant motivation involved in exercise stress testing, it would also be of additional benefit to obtain accurate predictions of $\dot{V}O_2$max from a single submaximal exercise trial. In this regard, Faulkner et al. (2007) observed that the power outputs elicited from single perceptually-regulated bouts of exercise (production protocol), corresponding to RPE 13 and 15, were significantly correlated with $\dot{V}O_2$max and maximal power output.

3.2.4 Purpose and hypotheses:

The purpose of this study was to compare the prediction of $\dot{V}O_2$max from four submaximal exercise procedures with measured $\dot{V}O_2$max, on a cycle ergometer. As such, an estimation and production protocol (up to RPE 13), Keele Lifestyle RPE nomogram and Å-R nomogram were employed with men and women of low-fitness. It was hypothesised that the procedures involving the RPE would provide predictions of $\dot{V}O_2$max that were at least as accurate as-, or more accurate than the Å-R nomogram.

3.3 Method:

3.3.1 Participants:

Eleven men and 13 women of low-fitness volunteered for this study (Table 3.1). Participants were informed of the current investigation using an information sheet (Appendix 1a) attached to a recruitment email. Prior to participation, each volunteer provided written informed consent (Appendix 2a), and completed both a General Health Questionnaire (Appendix 3) and Current Health Questionnaire (Appendix 4) to establish their health status. All participants were healthy, asymptomatic of illness, and free from any acute or chronic injury or disease. Participants involved in the study were deemed to be of low-fitness following self-reports concerning their activity status (no structured physical activity in the six months prior to the research study). This was confirmed retrospectively using the Shvartz and Reibold (1990) age- and gender-specific aerobic fitness norms. Research was conducted in agreement with the guidelines and testing policies of the Ethics Committee of the School of Sport and Health Sciences at the University of Exeter.

Table 3.1. Descriptive statistics, including age (y), height (cm), body mass (kg), percent body fatness (as measured by bioelectrical impedance analysis: BIA), systolic- (SBP; mmHg) and diastolic blood pressure (DBP; mmHg), for men and women. Values are mean ± SD.

	Age (y)	Height (cm)	Body mass (kg)	BIA (%)	SBP (mmHg)	DBP (mmHg)
Men	31.3 ± 9.0	180.0 ± 4.1	81.3 ± 12.1	19.9 ± 7.7	125.4 ± 7.9	79.9 ± 4.5
Women	40.8 ± 12.7	164.0 ± 5.3	64.6 ± 10.2	27.5 ± 6.5	124.5 ± 7.7	77.7 ± 5.1

3.3.2 General procedures for cycle ergometry testing:

Each participant performed three laboratory-based exercise tests on an electronically-braked cycle ergometer (Lode Excalibur Sport V2, Lode BV, Groningen, The Netherlands), separated by a 48 to 72 h recovery period. These included a maximal test (GXT to establish $\dot{V}O_2$max), and two submaximal tests (RPE production protocol; Å-R test) which were performed in a randomised order. Participants reported their overall perception of exertion during the exercise tests using the Borg (1998) 6-20 RPE scale. The 15-point scale incorporates nine verbal descriptors ranging from 'no exertion at all' (RPE 6) to 'maximal exertion' (RPE 20). A rating of 6 corresponds to the level of exertion experienced during quiet seated rest, whilst a rating of 19 approximates maximal or near-maximal physical exertion. Written and verbal Instructions on how to use the Borg 6-20 scale during the estimation procedure (as detailed in Borg, 1998) were provided prior to the start of the exercise test. Participants had no prior experience of perceptual scaling with the Borg 6-20 RPE scale, and any questions regarding its use were addressed at this time. Submaximal RPE data collated during the maximal GXT provided a prediction of $\dot{V}O_2$max (estimation protocol). Heart rate (HR) and RPE data collected during the Å-R test enabled two further predictions of $\dot{V}O_2$max (Å-R nomogram & Keele Lifestyle nomogram [Appendix 5], respectively). The final predictive procedure utilised a production protocol which involved cycling at perceptually-regulated intensities equating to RPE 9, 11 and 13, according to the Borg scale. Similarly, written and verbal instructions were provided as to the use of the Borg 6-20 scale during the production procedure, which were modified accordingly from Borg (1998). Participants refrained from exercise (except for walking) during each recovery period. Resistance on the cycle ergometer was manipulated using the Lode workload programmer, accurate to ± 1 W, which was independent of pedal cadence. The display screen specifying the resistance of the cycle ergometer was masked from the participants' view at all times. Pedal cadence was maintained at 60 rev·min^{-1} throughout each exercise test. This was in accordance with previous research that suggests that low pedal cadences (< 60 rev·min^{-1}) influence the magnitude of the local sensations of exertion (Jameson & Ring, 2002). Pedal frequency was displayed on a separate screen. Seat height and handle bar position were established and noted before the first exercise test and remained the same for each test thereafter. On-line respiratory gas analysis occurred every 10-s throughout each exercise test via a breath-by-breath automatic gas calibrator system (Cortex Metalyzer II, Biophysik, Leipzig, Germany). The system was calibrated prior to each test in accordance with manufacturer's guidelines using a 3-L syringe for volume calibration and an ambient air measurement for gas calibration (Gas 1; O_2: 20.93, CO_2: 0.03 vol %; Gas 2; O_2: 14.98, CO_2: 5.04 vol %). Expired air was collected continuously using a facemask to allow participants to verbally communicate with the experimenters. A wireless chest strap telemetry system

(Polar Electro T31, Kempele, Finland) recorded HR continuously during each exercise test. All physiological outputs ($\dot{V}O_2$, HR, respiratory exchange ratio: RER) were concealed from the participant for the duration of each test.

Prior to the initial exercise test, the participants' height, body mass, (SECA, Hamburg, Germany), body fat (Tanita, Body Composition Analyzer, BF-350, Tokyo, Japan) and blood pressure (Accoson, London, England) were measured. On the initial visit to the laboratory, participants were introduced to the Borg 6-20 RPE scale (Borg, 1998). Recent findings suggest that the overall sensation of exertion provides a more reliable and accurate prediction of $\dot{V}O_2$max than peripheral sensations of exertion (Faulkner & Eston, 2007). Thus, overall exertion was reported during each exercise test. Standardised instructions on how to implement the scale during the three exercise tests were given (Borg, 1998). There was no period of active familiarisation with the scale prior to participation. The scale was in full view of the participant for the duration of each test.

3.3.3 Exercise tests:

a) Graded exercise test to establish $\dot{V}O_2$max (estimation):

The graded exercise test to establish $\dot{V}O_2$max was continuous and incremental in style, commencing at 40 W and increasing by 40 W every 3 minutes until $\dot{V}O_2$max. During the final 30-s of each increment of the GXT, the participant reported their current overall RPE. These submaximal RPE values, estimated throughout the exercise test (estimation protocol), were subsequently utilised to provide a prediction of $\dot{V}O_2$max. Termination of the exercise test resulted from the attainment of one or more of the following criteria for achieving $\dot{V}O_2$max: a plateau in oxygen consumption (± 150 ml·min^{-1}), a HR within ± 10 b·min^{-1} of the age-predicted maximum, an RER that was equal to- or exceeded 1.15, a failure to maintain the required pedal cadence, or if the participant reported volitional exhaustion (Cooke, 2008). After completing the exercise test, participants cycled against a light resistance to aid recovery. Due to the 'light' intensity employed during the initial stages of the GXT, a warm-up was not implemented.

b) Perceptually-regulated graded exercise test (production):

The submaximal production protocol consisted of three perceptually-regulated exercise intensities, 9, 11 and 13 according to the Borg 6-20 RPE scale, being prescribed in that order. Participants were initially instructed to cycle at an intensity that was equivalent to an effort of RPE 9. Within a 2-min habituation period, participants instructed the experimenters to adjust the resistance until they were satisfied that the exercise intensity equated to RPE 9. Participants then cycled at that intensity for 3-min. No further intensity adjustments were made unless requested by the participant. At the end of the 3-min, the participant instructed the experimenters to adjust the exercise intensity so that an RPE 11 was attained. An initial increment of 25 W was used when increasing the power output between the RPE stages. Further increases in power output were applied in increments of 10 W and 5 W until the target RPE was attained. If the target RPE was exceeded, power output was adjusted in decrements of 10 W and 5 W. This process was also repeated for an RPE 13. Participants had a 5-min cool down period following completion of the exercise test. Again, a warm-up period was not included in the test due to reasons stipulated in the GXT to $\dot{V}O_2$max. The submaximal $\dot{V}O_2$ values elicited at each of the three RPE production levels (9, 11 & 13) were extrapolated to RPE 20 (theoretical maximal RPE) and RPE 19 (average peak RPE value reported at the termination of the GXT to $\dot{V}O_2$max) to predict $\dot{V}O_2$max.

c) Modified Åstrand-Ryhming (Å-R) test (incorporating the Keele-Lifestyle RPE procedures):

There was no period of familiarisation (warm-up) prior to the Å-R test (Åstrand & Ryhming, 1954). A pilot study involving six men and three women was undertaken to assess whether the WR suggested by the ACSM (2010) would be suitable for a sample of low-fit men and women. Although the upper threshold suggested by the ACSM was suitable for women of low-fitness (75 W), the suggested WR for men of low-fitness (50 or 100 W) did not allow HR to exceed the specified threshold (> 125 $b \cdot min^{-1}$) that would enable an acceptable prediction of $\dot{V}O_2$max. Manipulation of the exercise intensity during the pilot study suggested that a WR of 130 W was more appropriate for men of low-fitness, for the age range involved in this study. Consequently, during the Å-R test, men and women cycled at a constant pedal cadence (60 $rev \cdot min^{-1}$) for 6 minutes at 130 W and 75 W, respectively. According to the Å-R criteria, HR was required to be between 125 – 170 $b \cdot min^{-1}$ within the 5th and 6th minute of the test. An additional minute was administered if the HR did not exceed 125 $b \cdot min^{-1}$ in the final minute of the exercise test, as per the original instructions. If the participant's HR was not within the desired range during the final two minutes of the exercise test (6^{th} – 7^{th} minute), the test was terminated. Participants reported the RPE at the completion of each minute of the exercise test to enable a prediction of $\dot{V}O_2$max from the Keele-Lifestyle RPE nomogram (Buckley et al., 1998). Heart rate and $\dot{V}O_2$ were recorded continuously, and a cool down period was administered following the completion of the test at the discretion of each participant. The single modified Å-R test therefore facilitated two submaximal predictions of $\dot{V}O_2$max (Å-R nomogram & Keele Lifestyle RPE nomogram).

3.3.4 Data analysis:

a) Methodology to predict $\dot{V}O_2max$ using the RPE:

The mean $\dot{V}O_2$ (ml·kg^{-1}·min^{-1}) values collated over the final 30-s of each stage of the GXT to $\dot{V}O_2$max (estimation protocol; EST) and the RPE production protocol (PROD), were used in the subsequent analyses. Firstly, linear regression analysis was used to determine the submaximal $\dot{V}O_2$ value which corresponded to an RPE of 13 ($\dot{V}O_2$ = a + b (RPE_{13})) during the estimation test. Individual linear regression analyses using the submaximal $\dot{V}O_2$ values elicited prior to- and including an RPE 13 for the estimation and perceptually-regulated exercise tests were extrapolated to an RPE of 19 (peak terminal RPE; EST_{19}, $PROD_{19}$, respectively), and 20 (theoretical maximal RPE; EST_{20}, $PROD_{20}$, respectively), to enable a prediction of $\dot{V}O_2$max (ml·kg^{-1}·min^{-1}). An RPE 19 is often employed as an extrapolation end-point similar to RPE 20, as previous research has demonstrated that the theoretical maximal RPE is infrequently reported at volitional exhaustion by adults (Eston, Faulkner, St Clair Gibson, Noakes, & Parfitt, 2007; St Clair Gibson, Lambert, Hawley, Broomhead, & Noakes, 1999) and children alike (Barkley & Roemmich 2008).

b) Methodology to predict $\dot{V}O_2max$ using the Åstrand-Ryhming nomogram:

The Å-R nomogram (Åstrand & Ryhming, 1954; Åstrand, 1960) provided a prediction of $\dot{V}O_2$max based on the average submaximal heart rate (125 – 170 b·min^{-1}) recorded during the 5th and 6th minute (or 6th & 7th, accordingly) of the Å-R test and the corresponding WR. Age correction factors were applied to account for the decrease in age-predicted maximal HR with increasing age, according to the original methods of Åstrand (1960) and as described by the ACSM (2010). The subsequent $\dot{V}O_2$max prediction (reported as an absolute $\dot{V}O_2$max value; L·min^{-1}) was transformed into a relative value (ml·kg^{-1}·min^{-1}) to aid the comparison of accuracy between the predictive models.

c) Methodology to predict $\dot{V}O_2max$ using the Keele-Lifestyle RPE nomogram:

The RPE and corresponding WR recorded at the termination of the Å-R test, combined with the associated correction factor reported by Buckley et al. (1998), enabled an estimate of $\dot{V}O_2$max using the RPE nomogram. However, as the RPE nomogram was devised to be employed alongside the Å-R test, and the Å-R test predicts $\dot{V}O_2$max in absolute values, it follows that the prediction of $\dot{V}O_2$max using the RPE nomogram is also reported in absolute terms. Consequently, a relative $\dot{V}O_2$max value was computed for each participant in this study using the RPE nomogram data.

3.3.5 Statistical Analyses:

Individual coefficients of determination (R^2), obtained following linear regression analysis on the $\dot{V}O_2$ and RPE data prior to- and including RPE 13, were converted to Fisher *Zr* values to approximate the normality of the sampling distribution during the estimation and production protocols (Thomas & Nelson, 1996; Appendix 6).

A one sample *t* test compared the average RPE reported at the termination of the Å-R test with the average submaximal RPE used in the prediction of $\dot{V}O_2$max from the estimation and production exercise tests (RPE 13).

a) Comparison of measured- and predicted $\dot{V}O_2max$:

A one-factor repeated measures ANOVA was used to compare measured $\dot{V}O_2$max with predictions of $\dot{V}O_2$max from the Å-R nomogram, Keele Lifestyle RPE nomogram, estimation (EST_{19}, EST_{20}) and production exercise tests ($PROD_{19}$, $PROD_{20}$)

for both men and women. Where assumptions of sphericity were violated, the critical value of F was adjusted by the Greenhouse-Geisser epsilon value from the Mauchley test of sphericity. Where significant differences were reported between measured- and predicted $\dot{V}O_2$max, post-hoc analyses in the form of paired samples t tests were performed using a Bonferroni adjustment ($P < 0.008$) to protect against type I error. Alpha was set at 0.05 and adjusted accordingly. Intra-class correlation coefficients (ICC) were calculated via the two-way mixed effects model to quantify the reproducibility between measured- and predicted $\dot{V}O_2$max. A Bland and Altman (1986) 95 % limits of agreement (LoA) analysis quantified the agreement (bias and random error) between measured $\dot{V}O_2$max and each predicted $\dot{V}O_2$max.

b) Comparison of absolute and relative exercise intensities between submaximal tests:

A series of one-factor ANOVAs were used to identify differences in the absolute- ($\dot{V}O_2$, HR, WR) and relative (%$\dot{V}O_2$max, %HRmax) exercise intensities reported at the termination of the Å-R test and at an RPE 13 in the estimation and production tests. Paired sample t tests were used to assess differences in %$\dot{V}O_2$max and %HRmax between men and women for each of the submaximal exercise tests.

All data were analyzed using the statistical package SPSS for Windows, PC software, version 13.

3.4 Results:

The physiological ($\dot{V}O_2$max, HRmax, RER), physical (WR), and perceptual (RPE) values reported at the termination of the GXT to $\dot{V}O_2$max, are shown in Table 3.2.

Table 3.2. Maximal physiological (oxygen uptake: $\dot{V}O_2$; heart rate: HR; respiratory exchange ratio: RER), physical (work rate: WR) and perceptual (ratings of perceived exertion: RPE) responses at termination of the graded-exercise test.

	$\dot{V}O_2$max ml·kg^{-1}·min^{-1}	HRmax b·min^{-1}	RER	Maximal WR (W)	Terminal RPE
Men	39.0 ± 4.7	189 ± 8	1.21 ± 0.06	256.0 ± 20.7	18.9 ± 0.6
Women	29.8 ± 5.4	179 ± 11	1.20 ± 0.09	155.4 ± 30.4	19.3 ± 1.1

The transformed R^2 values calculated from (typically) three submaximal $\dot{V}O_2$ data points elicited prior to- and including an RPE 13 produced average Fisher *Zr* values of 2.42 ± 0.61 and 2.33 ± 0.58 for the estimation and production exercise tests, respectively. When reconverted, these revealed a strong relationship between the RPE and $\dot{V}O_2$ values for both the estimation ($R^2 = 0.97 \pm 0.38$) and production exercise tests ($R^2 = 0.97 \pm 0.38$). A one sample *t* test revealed no differences ($t_{(23)} = -.42$, $P > 0.05$) between the RPE reported at the termination of the Å-R test (12.8 ± 2.0) and an RPE 13.

3.4.1 Comparison of measured- and predicted $\dot{V}O_2$max:

A one-way ANOVA revealed no significant differences between measured- and predicted $\dot{V}O_2$max (Å-R nomogram, Keele-Lifestyle RPE nomogram, EST_{19}, EST_{20}, $PROD_{19}$, $PROD_{20}$) for men ($F_{(1.7,\ 17.3)} = .69$, $P > 0.05$). The mean (± SD) measured- (38.9 ± 4.0 ml·kg^{-1}·min^{-1}) and predicted $\dot{V}O_2$max values were 39.3 ± 9.2, 38.6 ± 5.2, 38.2 ± 10.3, 35.9 ± 9.2, 37.3 ± 4.5 and 35.1 ± 4.2 ml·kg^{-1}·min^{-1}, respectively (Figure 3.1).

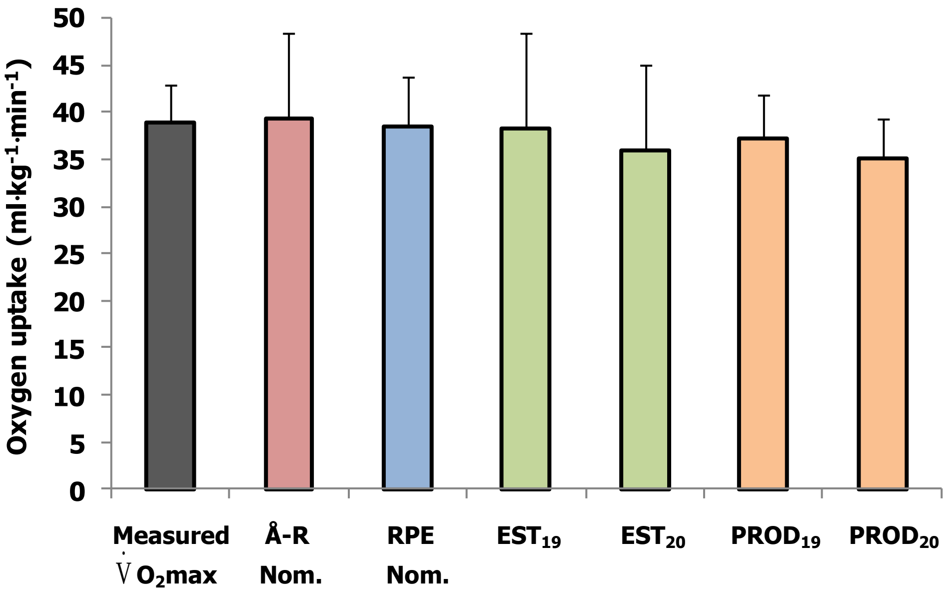

Figure 3.1. Comparison of measured- and predicted maximal oxygen uptake ($\dot{V}O_2$max; ml·kg^{-1}·min^{-1}) for each of the six predictive methods, for men. Values are mean ± SD.

However, a significant difference was observed between measured- and predicted $\dot{V}O_2$max for women ($F_{(2.5,\ 30.5)}$ = 4.94, P < 0.05). The mean (± SD) measured- (29.8 ± 5.4 ml·kg^{-1}·min^{-1}) and predicted $\dot{V}O_2$max was 37.2 ± 11.2, 27.3 ± 8.9, 31.8 ± 5.8, 30.2 ± 5.5, 28.8 ± 4.7 and 27.4 ± 4.4, respectively. As demonstrated in Figure 3.2, post-hoc analyses revealed that the Å-R nomogram was approaching statistical significance by overestimating $\dot{V}O_2$max in women ($t_{(12)}$ = -3.08; P = 0.01).

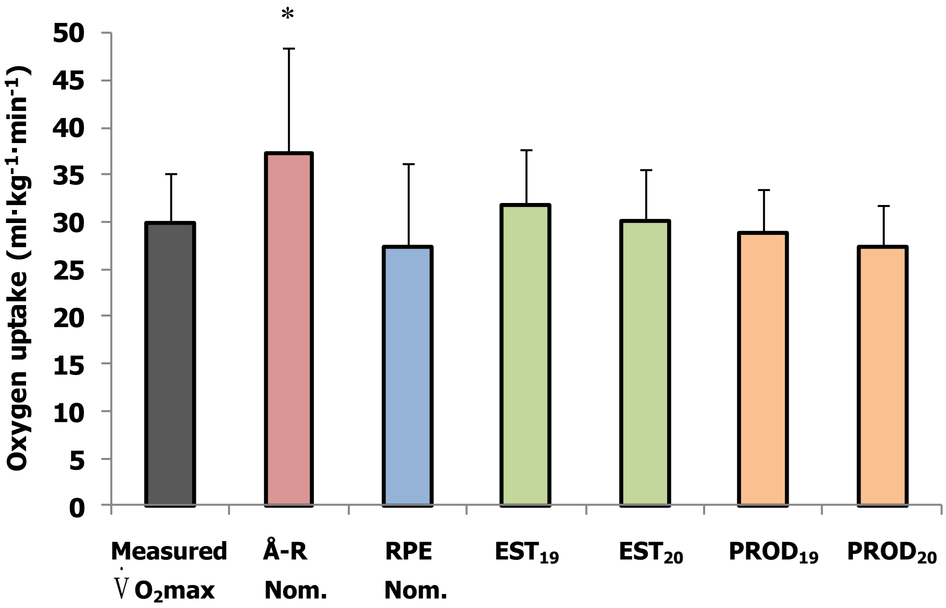

Figure 3.2. Comparison of measured- and predicted maximal oxygen uptake ($\dot{V}O_2$max; ml·kg^{-1}·min^{-1}) for each of the six predictive methods, for women. Values are mean ± SD.

* Approaching statistical significance (P = 0.01) between measured $\dot{V}O_2$max and predicted $\dot{V}O_2$max from the Åstrand-Ryhming nomogram.

The agreement between the measured- and predicted $\dot{V}O_2$max (ICC & 95 % LoA) can be observed in Table 3.3.

Table 3.3. The intraclass correlation coefficients (ICC; *R*) and 95 % limits of agreement (LoA; ml·kg^{-1}·min^{-1}) analysis between measured- and predicted $\dot{V}O_2$max (ml·kg^{-1}·min^{-1}) for men (n = 11) and women (n = 13).

		Å-R Nomogram	**RPE Nomogram**	**EST_{20}**	**EST_{19}**	**$PROD_{20}$**	**$PROD_{19}$**
Men	**ICC**	0.63	0.69	0.59	0.63	0.61	0.60
	LoA	-0.4 ± 13.7	1.3 ± 9.0	3.4 ± 13.1	0.9 ± 11.4	-1.7 ± 8.9	-3.9 ± 8.5
Women	**ICC**	0.68	0.68	0.76	0.77	0.77	0.77
	LoA	2.6 ± 13.7	2.6 ± 14.2	1.9 ± 9.7	0.4 ± 9.3	1.0 ± 8.5	2.7 ± 8.3

3.4.2 Comparison of absolute and relative exercise intensities between submaximal tests:

A one-factor ANOVA demonstrated no significant differences in the exercise intensity (WR) at the conclusion of the Å-R test, and at an RPE 13 in the estimation and production exercise tests, for both men ($F_{(2, 20)} = 3.00$, $P > 0.05$) and women ($F_{(2, 24)} = 2.90$, $P > 0.05$). A subsequent series of one-factor repeated-measures ANOVA demonstrated no significant differences ($P > 0.05$) between the $\dot{V}O_2$ (ml·kg^{-1}·min^{-1} or %$\dot{V}O_2$max) or HR (b·min^{-1} or %HRmax) recorded at the end of the Å-R test and at an RPE 13 during either the estimation or production protocols, for men and women (Table 3.4).

Table 3.4. Comparison between oxygen uptake ($\dot{V}O_2$; ml·kg^{-1}·min^{-1}; %$\dot{V}O_2$ maximum), heart rate (HR; b·min^{-1}; %HR maximum) and work rate (WR) recorded at termination of the Åstrand-Ryhming nomogram (Å-R) and at an RPE 13 during both the estimation (EST) and production (PROD) exercise protocols. Values are mean ± SD.

		$\dot{V}O_2$ (ml·kg^{-1}·min^{-1})	$\dot{V}O_2$max (%)	HR (b·min^{-1})	HRmax (%)	WR
Men	Å-R	21.8 ± 5.3	70.8 ± 8.7	141 ± 14	79.4 ± 8.7	130 ± 0
	EST	20.5 ± 4.3	68.9 ± 9.6	141 ± 11	78.8 ± 6.6	124 ± 8
	PROD	19.0 ± 2.6	64.6 ± 8.5	139 ± 13	77.7 ± 8.9	116 ± 5
Women	Å-R	25.8 ± 4.6	66.2 ± 8.2	140 ± 15	75.7 ± 7.6	75 ± 0
	EST	22.0 ± 3.9	59.9 ± 12.2	136 ± 24	72.0 ± 12.0	85 ± 4
	PROD	22.0 ± 2.0	57.0 ± 6.1	132 ±14	69.6 ± 6.7	79 ± 4

3.5 Discussion:

The aim of this study was to assess whether the ratings of perceived exertion, corresponding to a low-moderate exercise intensity, could be used to provide accurate predictions of $\dot{V}O_2$max in men and women of low-fitness when compared to the

Åstrand-Ryhming nomogram. The findings of this study confirmed the utility of the RPE in providing accurate estimates of $\dot{V}O_2$max in men and women, in keeping with previous research (Eston et al., 2005, 2006, 2008; Faulkner & Eston, 2007; Faulkner et al., 2007). Indeed, predictions of $\dot{V}O_2$max using submaximal RPE were as good as, if not better than those from the Å-R nomogram. Interestingly, a novel finding of this study was that accurate predictions of $\dot{V}O_2$max may be obtained from a single, low-moderate exercise session. This provides further support to the notion that RPE is highly correlated with $\dot{V}O_2$ at low-moderate RPE intensities (Faulkner & Eston, 2007; Faulkner et al., 2007).

3.5.1 Accuracy of $\dot{V}O_2$max predictions:

According to the mean data, the RPE nomogram was the most accurate predictor of $\dot{V}O_2$max in men, closely followed by the Å-R nomogram, of which both underestimated $\dot{V}O_2$max to within 1 % of the measured value. When considering the accuracy of the estimation and production procedures, mean estimates of $\dot{V}O_2$max were within 2 – 10 % of the measured value. For women, the RPE procedures (EST_{19}, EST_{20}, $PROD_{19}$, $PROD_{20}$) estimated $\dot{V}O_2$max to within 1 – 8 % of measured $\dot{V}O_2$max, whereas, the Å-R nomogram overestimated $\dot{V}O_2$max by approximately 25 %. This is in agreement with previous research that has demonstrated the Å-R nomogram to overestimate the $\dot{V}O_2$max of women by ~20 % during cycle ergometry (Siconolfi, Garber, Lasater, & Carleton, 1985; Zwiren et al., 1991).

3.5.2 Consistency of $\dot{V}O_2$max predictions:

For appropriate inferences to be made, however, it is necessary to consider the reliability of the estimates of $\dot{V}O_2$max from each of the predictive methods. As can be seen from Table 3.3, the Keele-lifestyle nomogram was most accurate for the men in this study, whereas, the perceptually-regulated (PROD) exercise test revealed the greatest consistency between measured- and predicted $\dot{V}O_2$max for women. This is shown by the relatively comparable ICCs, but in particular by the narrowest LoA observed across all six of the predictive methods. Although the submaximal procedures (production & Å-R test) were randomised, each participant performed the exhaustive (estimation) GXT first. Thus, despite the known differences in the perceptual processes of these two procedures (*passive* estimation cf. *active* production), it is plausible that the improved consistency in estimates provided during the production procedure may in part be the result of familiarisation to the use of the RPE. In this regard, substantially wider LoA were revealed for the estimation test in men. Although the LoA were also wider for the women in this study, it was not to the same extent as observed with the men. Indeed, this study demonstrated that a 27 – 30 % margin of error may be observed in the prediction of $\dot{V}O_2$max when employing the RPE during estimation or production procedures with low-fit men, or 24 – 28 % with low-fit women. The Å-R nomogram demonstrated inflated LoA for both men and women, which, in a worst case scenario, may result in a 35 – 36 % error in prediction of $\dot{V}O_2$max. Interestingly, although the RPE nomogram proved the most reliable method for men (21%), it provided the least reliable predictions for women (up to 36 % margin of error).

3.5.3 Limitations of the Keele-Lifestyle RPE nomogram:

This is the first study to provide independent support for the use of the Keele-Lifestyle RPE nomogram (Buckley et al., 1998) as an acceptable means of predicting $\dot{V}O_2$max, at least in low-fit men. Such a nomogram may be of value to a clinician, given that accurate predictions of $\dot{V}O_2$max may be obtained following a 6-min bout of exercise. However, it is clear that the nomogram contains a fundamental error. The estimation of the fractions of $\dot{V}O_2$max elicited at each successive RPE in the left hand column of the nomogram (pr$\dot{V}O_2$max: RPE), particularly at the lower and moderate RPE values, are too high. These fractions are overestimated by approximately 10 %. The overestimation of pr$\dot{V}O_2$max: RPE during cycle ergometry is confirmed by previous and current research on healthy individuals (Eston & Williams, 1988; Eston et al., 2005, 2008; Faulkner & Eston, 2007; Faulkner et al., 2007).

3.5.4 Methodological considerations when using the Åstrand-Ryhming test and both estimation and production procedures:

The results of this study offer further evidence that the RPE provides predictions of $\dot{V}O_2$max that are similar to-, or better than heart rate (Faulkner et al., 2007; Morgan & Borg, 1976). The RPE has been shown to be more strongly correlated with physiological markers of exertion ($\dot{V}O_2$ & HR) at higher exercise intensities (Eston et al., 2005, 2006, 2008; Faulkner et al., 2007). As such, slightly less accurate estimates of $\dot{V}O_2$max have been generated when predicting $\dot{V}O_2$max from a lower perceptual range (i.e. RPE 9–13; Faulkner et al., 2007). As expected, the ICCs between measured- and predicted $\dot{V}O_2$max revealed in this study were lower than those reported previously. A greater degree of agreement between measured- and predicted $\dot{V}O_2$max may be obtained following a period of familiarisation, or when utilising higher perceptual ranges (i.e. 9–17; Eston et al., 2005, 2006, 2008; Faulkner et al., 2007). Exercise tests that terminate at such submaximal intensities (i.e. RPE 13) may be considered beneficial for individuals of low-fitness, especially as low-fit individuals are more likely to be negatively affected by the demand of high intensity exercise (Hardy & Rejeski, 1989; Parfitt & Eston, 1995; Parfitt et al., 1996). Men and women in this study chose to exercise between 57 – 69 % of $\dot{V}O_2$max when requested to perform a single exercise session up to an RPE 13. These intensities are similar to those reported by Eston et al. (2005) and Faulkner et al. (2007).

In this study, the Åstrand-Ryhming test was modified for men to ensure that HR achieved the specified range (125 – 170 b·min^{-1}) to facilitate a prediction of $\dot{V}O_2$max. The consequence of this was to ultimately increase power output to 130 W, which was above the recommended level of 100 W (ACSM, 2010). The average HR that corresponded to the given power output (130 W) was 140 b·min^{-1}. This is commensurate with Davies' (1968) findings, in that predictions of $\dot{V}O_2$max are more accurate from a submaximal HR in the range 140 – 180 b·min^{-1}.

The duration of the perceptually-regulated protocol was longer than the Åstrand-Ryhming test (6 – 7 min) due to the three stage nature of the exercise test. On average, a production intensity of an RPE 13 was attained after approximately 11-min. During the GXT (estimation), an RPE 13 was reported on average at ~6-min and ~9-min from the onset of exercise, for women and men, respectively. Despite a slightly longer duration, the estimation and production exercise tests may prove a more appropriate indicator of aerobic fitness than the Åstrand-Ryhming test, on the basis that more reliable estimates of $\dot{V}O_2$max may be obtained from a comparable physiological and perceptual work load.

3.5.5 Extrapolation to theoretical maximal RPE cf. peak terminal RPE:

The present study concurs with previous research that have observed RPE values that are less than the theoretical maximal RPE of 20 at maximal exertion (Eston et al., 2007; Faulkner & Eston, 2007; Faulkner et al., 2007; Noakes, St Clair Gibson, & Lambert, 2004; St Clair Gibson et al., 1999). However, in accordance with Faulkner and Eston (2007), extrapolation of submaximal $\dot{V}O_2$ from RPE values prior to- and including an RPE 13 to theoretical maximal RPE (20) during the production tests provided a more accurate prediction of $\dot{V}O_2$max in comparison to extrapolation to a peak terminal RPE of 19. Conversely, during the estimation exercise test, extrapolation of submaximal variables to terminal RPE (19) elicited more accurate estimates of $\dot{V}O_2$max. Interestingly, previous research has suggested that extrapolation to an RPE of 19 may provide more accurate predictions of $\dot{V}O_2$max, yet this has been demonstrated for exercise to a higher perceptual intensity (i.e. RPE 17; Eston et al., 2006; Faulkner et al., 2007). It is therefore feasible that during low intensity, perceptually-regulated exercise, participants employ a perceptual framework that utilises the maximal value of RPE 20 as an upper reference point to which they gauge their perception of exertion, and thus their corresponding work rate. However, during estimation procedures, it is likely that this perceptual frame of reference is modified throughout an exercise bout, such that during high intensity exercise (i.e. RPE 17) the theoretical maximal end-point (RPE 20) may be considered unattainable. It would appear that further research is necessary to examine the rate of change in RPE at low, moderate and severe exercise intensities, and the individual setting of the maximal RPE of these intensities.

3.6 Conclusion:

Each of the predictive methods utilised in this study, including the Åstrand-Ryhming nomogram, KeeleLifestyle RPE nomogram, estimation and production protocols, provided estimates of $\dot{V}O_2$max that were not dissimilar to measured values, in low-fit men and women. However, it is pertinent to recognise that the limits of agreement analyses employed in this study highlighted significant variability in $\dot{V}O_2$max estimations from a number of these submaximal procedures.. Nevertheless, the results of the present study offer further support to the utility of the ratings of perceived exertion in providing accurate predictions of maximal oxygen uptake (Eston et al., 2005, 2006, 2008; Faulkner & Eston, 2007; Faulkner et al., 2007). Although somewhat less accurate than a procedure employing repeat-trials, this study has shown that a single, submaximal exercise session incorporating the RPE (estimation or production) may prove an appropriate means of gauging the maximal functional capacity of healthy men and women of low-fitness. It would be useful however to investigate whether a differing exercise protocol (i.e. employing continuous increments in work rate) may facilitate more accurate predictions of $\dot{V}O_2$max, whilst reducing associated ‘costs’ (time; monetary; motivational) involved in an exercise test. Further research is required to identify whether the reliability of predicting $\dot{V}O_2$max using the rating of perceived exertion may be improved in low-fit individuals.

Chapter 4

Study 2

Prediction of maximal oxygen uptake from submaximal ratings of perceived exertion and heart rate during a continuous exercise test: the efficacy of RPE 13

This study has contributed to the following publication and presentation:

Publication:

Lambrick, D.M., Faulkner, J.A., Rowlands, A.V., & Eston, R.G. (2009). Prediction of maximal oxygen uptake from submaximal ratings of perceived exertion and heart rate during a continuous exercise test: the efficacy of RPE 13. *European Journal of Applied Physiology*, 107, 1-9.

Poster presentation:

Lambrick, D.M., Faulkner, J.A., Rowlands, A.V., & Eston, R.G. (2009). Prediction of maximal oxygen uptake from submaximal ratings of perceived exertion and heart rate during a continuous exercise test: the efficacy of RPE 13. The Annual New Zealand Sports Medicine and Science conference (Rotorua, New Zealand, 13th November, 2009).

4.1 Abstract:

This study assessed the utility of a single, continuous exercise protocol in facilitating accurate estimates of maximal oxygen uptake ($\dot{V}O_2$max) from submaximal heart rate (HR) and the ratings of perceived exertion (RPE) in healthy, low-fit women, during cycle ergometry. Eleven women estimated their RPE during a continuous test (1 W · 4 s^{-1}) to volitional exhaustion (measured $\dot{V}O_2$max). Individual gaseous exchange thresholds (GETs) were determined retrospectively. The RPE and HR values prior to- and including an RPE 13 and GET were extrapolated against corresponding oxygen uptake to a theoretical maximal RPE (20) and peak RPE (19), and age-predicted HRmax, respectively, to predict $\dot{V}O_2$max. There were no significant differences (P > 0.05) between measured (30.9 ± 6.5 ml·kg^{-1}·min^{-1}) and predicted $\dot{V}O_2$max from all six methods. Limits of agreement were narrowest and intraclass correlations were highest for predictions of $\dot{V}O_2$max from an RPE 13 to peak RPE (19). Prediction of $\dot{V}O_2$peak from a regression equation using submaximal HR and work rate at an RPE 13 was also not significantly different to actual $\dot{V}O_2$max (P > 0.05, R^2 = 0.78, SEE = 3.42 ml·kg^{-1}·min^{-1}). Accurate predictions of $\dot{V}O_2$max may be obtained from a single, continuous, estimation exercise test to a moderate intensity (RPE 13) in low-fit women, particularly when extrapolated to peak terminal RPE (RPE_{19}). The RPE is a valuable tool that can be easily employed as an adjunct to HR, and provides supplementary clinical information that is superior to using HR alone.

4.2 Introduction:

4.2.1 Perceptual and physiological markers of exercise intensity:

The Borg (1998) 6-20 Ratings of Perceived Exertion (RPE) scale is a reliable measure used to quantify, monitor and assess an individual's exercise tolerance and level of exertion (ACSM, 2010). The strong relationship between the RPE and various physiological (oxygen uptake: $\dot{V}O_2$; heart rate: HR) and physical (work rate: WR) markers of exercise intensity are often demonstrated during *passive* estimation and perceptually-regulated (*active* production) procedures, as discussed in the review of literature.

Heart rate is often utilised by clinicians as an assessment tool within medical evaluations prior to beginning an exercise programme, or as a means of prescribing appropriate exercise intensities and monitoring progress during a period of training (ACSM, 2010). However, several factors (environmental, behavioural & dietary) can influence the submaximal heart rate response during exercise. The RPE scale has been advocated as an adjunct to heart rate in obtaining useful clinical information during exercise testing procedures (ACSM, 2010). Moreover, it has been suggested that the RPE obtained during a submaximal exercise test may better predict an individual's maximum heart rate than the generally-accepted equation of 220 – age (Johnson, Kline, Martin, & Powers, 1984; Johnson & Prins, 1991). Yet in practice, many still do not recognise the benefits of employing the RPE and so continue to rely on heart rate as the principal determinant of an individual's level of fitness and capacity for exercise.

Direct measurement of maximal oxygen uptake ($\dot{V}O_2max$) is the gold-standard method of assessing an individual's cardiorespiratory fitness and maximal capacity for exercise (Laukkanen et al., 2001). However, the high-intensity nature of exhaustive stress tests may be inappropriate for certain low-fit or patient groups. As such, submaximal exercise testing procedures are routinely used as a safe and practical means of determining the aerobic fitness of such individuals (Hellerstein, Hirsch, Ader, Greenblott, & Siegel, 1973; Johnson & Prins, 1991; Noonan & Dean, 2000; Sheffield & Roitman, 1976).

4.2.2 Considerations for the practical application of the ratings of perceived exertion in predicting maximal functional capacity:

Recent research by Eston and colleagues (Eston et al., 2005, 2006, 2008; Faulkner et al., 2007) has focussed on identifying whether a perceptually-regulated graded exercise test (GXT) may be utilised to obtain an accurate prediction of $\dot{V}O_2$max, and provide a means of prescribing exercise intensity across a range of production levels. There were no statistically significant differences between measured $\dot{V}O_2$max and $\dot{V}O_2$max predicted from the submaximal, perceptually-regulated exercise test in each of these aforementioned studies, regardless of gender and fitness (high- and low-fit). In these studies, $\dot{V}O_2$max was estimated by extrapolating the submaximal $\dot{V}O_2$ values from RPE ranges of either 9-13, 9-15, 9-17 or 11-17 to an RPE of 19 (peak RPE value frequently reported at termination of a GXT) and RPE 20 (theoretical maximal RPE).

Unsurprisingly, the most accurate predictions of $\dot{V}O_2$max are often attained following extrapolation of submaximal $\dot{V}O_2$ values prior to- and including an RPE 17 (Davies et al., 2008; Eston et al., 2005, 2006, 2008; Faulkner & Eston, 2007; Faulkner et al., 2007). During perceptually-regulated procedures, acceptable estimates of $\dot{V}O_2$max may be obtained from lower perceptual ranges (i.e. up to an RPE 13 or 15) following a period of familiarisation (Faulkner et al., 2007). However, as considered previously (study 1), for low-fit individuals, the benefit of obtaining accurate estimates of $\dot{V}O_2$max from a single-bout of exercise and from a lower perceptual range is evident. A single *estimation* test, which is continuous in nature and coupled with the exclusion of an RPE 17 may permit a reduction in test duration (in comparison to a perceptually-regulated protocol), which may have implications for the cost and time required to conduct a stress test, and would also necessitate less of an exertional and motivational effort by the exerciser. In this regard, the results of study 1 demonstrated that accurate estimates of $\dot{V}O_2$max may be obtained from a single estimation trial, up to- and including an RPE 13 in healthy, low-fit men and women.

4.2.3 Reliability of the RPE provided during estimation and perceptually-regulated exercise protocols:

In comparison to an estimation protocol, narrower limits of agreement (LoA) between measured- and predicted $\dot{V}O_2$max from an RPE 13 have been observed from a perceptually-regulated GXT, with low-fit men and women (study 1; Faulkner & Eston, 2007). In both studies, participants experienced either a 30 or 40 W incremental increase in exercise intensity every 3-min throughout a GXT to volitional exhaustion (estimation), in which they reported their perception of exertion in the final 30-s of each exercise bout. It is plausible to assume therefore that their perception of exertion may have differed throughout each 3-min period. In this regard, it is feasible to consider that a ramp-incremental protocol, whereby workload increases at a continual rate until the attainment of $\dot{V}O_2$max, may enable the rate of change in the RPE to be more closely monitored. Thus, more accurate predictions of $\dot{V}O_2$max and narrower LoA than those observed in previous studies (study 1; Faulkner & Eston, 2007) may potentially be obtained.

4.2.4 Practical / clinical application of the RPE:

It would be reasonable to assume that due to the continuous nature of a ramp-incremental protocol, an individual may attain an equivalent intensity to an RPE 13 in a relatively shorter period of time than during a 3-min step test. In study 1 of this thesis, low-fit men and women chose to exercise between 57 – 69 % of $\dot{V}O_2$max when requested to perform a single exercise session up to an RPE 13. However, the gas exchange threshold (GET) is often used as a non-invasive indicator of an individual's lactate threshold, and typically occurs at approximately 45 – 60 % of an individual's $\dot{V}O_2$max (Jones & Poole, 2005). Accordingly, it is feasible to assume that the GET occurs at a comparatively lower exercise intensity (during a shorter duration test) than at RPE 13. Therefore, it is of interest to investigate whether accurate estimates of $\dot{V}O_2$max may be obtained from the GET.

4.2.5 Purpose and hypotheses:

The purpose of this study was to assess whether a ramp-incremental protocol may facilitate accurate predictions of $\dot{V}O_2$max from an estimation procedure with low-fit women, during a single bout of moderate exercise on a cycle ergometer. It was hypothesised that a single ramp-incremental protocol would enable accurate predictions of $\dot{V}O_2$max and narrower LoA than those generated from the step protocols used in previous research (study 1; Faulkner & Eston, 2007). It was further hypothesised that accurate predictions of $\dot{V}O_2$max would be obtained from submaximal $\dot{V}O_2$ corresponding to both an RPE 13 and GET, and that the RPE would provide predictions of $\dot{V}O_2$max that were similar to- or more accurate than those obtained from age-predicted maximal heart rate. Moreover, it was hypothesised that GET would occur at relatively lower exercise intensity than would be experienced at RPE 13. Finally, it was hypothesised that a regression equation incorporating submaximal work rate at an RPE 13 and age-predicted maximal heart rate (as per the equation by Gellish et al., 2007) would also predict the $\dot{V}O_2$max of low-fit women with acceptable accuracy.

4.3 Method:

4.3.1 Participants:

Eleven healthy women (mean ± SD; age: 31.5 ± 10.8 y; height: 1.65 ± 0.06 m; body mass: 61.3 ± 8.1 kg) volunteered to take part in this study. Participants were informed of the current investigation using an information sheet (Appendix 1b) attached to a recruitment email. Participants were initially classified as being of ‘low fitness’ according to self-reported activity status (no structured physical activity in the preceding six months). This was confirmed retrospectively by comparing individual $\dot{V}O_2$max values to the Shvartz and Reibold (1990) age- and gender-specific aerobic fitness norms. All participants were asymptomatic of illness or disease and free from any acute or chronic injury, as established by the ACSM (2010) participant activity readiness questionnaire (PAR-Q; Appendix 7). Similarly, they were all classified as being of ‘low-risk’ for undertaking a maximal test to exhaustion according to the ACSM’s risk stratification procedures (ACSM, 2010; body mass index: 22.4 ± 3.3 $kg \cdot m^{-2}$; percent fat (bioelectrical impedance analysis): 26.8 ± 7.2 %; total cholesterol: 4.47 ± 0.90 $mmol^{-1}$; non-fasting blood glucose: 4.91 ± 0.81 $mmol^{-1}$; systolic blood pressure: 122.7 ± 7.6 mmHg; diastolic blood pressure: 78.5 ± 5.2 mmHg; Appendix 8). Each participant provided written informed consent (Appendix 2b) prior to participation. Research was conducted in agreement with the guidelines and testing policies of the Ethics Committee of the School of Sport and Health Sciences at the University of Exeter.

4.3.2 Procedures:

Each participant performed a single laboratory-based exercise test on an electromagnetically braked cycle ergometer (Lode Excallibur Sport, V2, Lode BV, Groningen, The Netherlands), to establish $\dot{V}O_2$max. The resistance on the cycle ergometer was manipulated using the Lode Workload Programmer, accurate to ± 1 W, which was independent of pedal cadence. Nevertheless, participants maintained a constant cadence of 60 $rev \cdot min^{-1}$ for the duration of the exercise test. Breath-by-breath sampling of respiratory gases occurred throughout the exercise test via an automatic gas calibrator system (Cortex Metalyzer II, Biophysik, Leipzig, Germany). The system was calibrated prior to each test in accordance with manufacturer's guidelines using a 3-L syringe for volume calibration and an ambient air measure for gas calibration. Heart rate was recorded continuously using a wireless chest strap telemetry system (Polar Electro T31, Kempele, Finland). Expired air was collected continuously using a facemask. All physiological ($\dot{V}O_2$, HR, respiratory exchange ratio: RER) and physical (WR) markers of exercise intensity were concealed from the participant at all times.

4.3.3 Measures:

Participants reported their overall perception of exertion during the exercise test using the Borg 6-20 RPE scale (Borg, 1998). Participants had no prior experience of perceptual scaling. Prior to the exercise test, participants were familiarised with the RPE scale and received standardised instructions (as per Borg, 1998) that provided specific commands on how to implement the scale. The RPE scale was in full view of each participant during the exercise test.

4.3.4 Health assessment:

Prior to the initial exercise test and in accordance with the ACSM risk stratification procedures for determining healthy but low-fit participants, basic anthropometric (height & body mass, SECA, Hamburg, Germany) and health measurements, including body fat (Tanita, Body Composition Analyzer, BF-350, Tokyo, Japan), blood pressure (Accoson, London, England), cholesterol and non-fasting blood glucose (Cardiochek P.A. & PTS PANELS test strips, Polymer Technology Systems Inc., Indianapolis, USA) were performed. Also, recent smoking history (current smoker or those who have quit within the last six months) and family history of myocardial infarction, coronary revascularisation, or sudden death in a first degree relative under the age of 65 years was assessed. If participants had two or more risk factors, as specified by the ACSM (2010), they were excluded from the study.

4.3.5 Graded exercise test to establish $\dot{V}O_2max$:

The GXT utilised a ramp-incremental protocol. This commenced with a 2-min baseline measurement at 0 W, after which the work rate increased at a rate of 1 W every 4-s (15 $W \cdot min^{-1}$) until $\dot{V}O_2$max. Termination of the exercise test was determined by a peak or plateau in oxygen consumption, the attainment of a HR within ± 10 $b \cdot min^{-1}$ of the conventional age-predicted maximum, an RER value that was equal to- or exceeded 1.15, a failure to maintain the required pedal cadence or if the participant reported volitional exhaustion (Cooke, 2008; Faria, Parker, & Faria, 2005). Participants reported their perception of exertion (RPE) every 2-min for the duration of the exercise test.

4.3.6 Determination of the gas exchange threshold (GET):

Individual gas exchange thresholds (GET) were subsequently determined from the $\dot{V}O_2$max data using a cluster of techniques. These included the $\dot{V}$-slope method (Beaver, Wasserman, & Whipp, 1986); which detects the onset of excess carbon dioxide (CO_2) production in response to lactate accumulation, and is denoted on the $\dot{V}O_2:\dot{V}CO_2$ plot as a disproportionate increase in $\dot{V}CO_2$ relative to the $\dot{V}O_2$. Similarly, ventilatory equivalents for oxygen ($\dot{V}_E/\dot{V}O_2$) and carbon dioxide ($\dot{V}_E/\dot{V}CO_2$) were utilised; with the GET signified as the point at which $\dot{V}_E/\dot{V}O_2$ begins to rise whilst $\dot{V}_E/\dot{V}CO_2$ is maintained or decreasing. It is noteworthy that the lag time in gaseous exchange variables (between the working muscles & the lungs) was accounted for when employing such techniques (Linnarsson, 1974). Once the GET had been identified, all data plots were assessed by trained and experienced investigators to ensure rigidity in the initial interpretation. Relative physical (WR), physiological ($\dot{V}O_2$, HR, RER) and perceptual (RPE) data corresponding to the GET were then utilised to obtain predictions of $\dot{V}O_2$max.

4.3.7 Data analysis:

a) Prediction of $\dot{V}O_2$max from RPE 13:

Where an RPE of 13 (according to the Borg Scale) had not been reported during the test, linear regression analysis was used to determine the corresponding submaximal $\dot{V}O_2$ value at RPE 13 ($\dot{V}O_2 = a + b\ (RPE_{13})$). Individual linear regression analyses using the submaximal $\dot{V}O_2$ values elicited prior to- and including an RPE 13 were extrapolated to an RPE of 19 (RPE_{19}; average peak RPE value reported at the termination of the exercise test), and 20 (RPE_{20}; theoretical maximal RPE) to obtain predictions of $\dot{V}O_2$max.

b) Prediction of $\dot{V}O_2$max from GET:

Firstly, linear regression analysis was employed on the RPE data in relation to work rate to establish RPE at the GET ($RPE_{GET} = a + b\ (WR_{GET})$). The RPE provided prior to- and at GET were then extrapolated against the corresponding $\dot{V}O_2$ data, to an RPE of 19 (GET_{19}) and an RPE of 20 (GET_{20}) to obtain further predictions of $\dot{V}O_2$max.

c) Prediction of $\dot{V}O_2$max from HR at RPE 13 and GET:

The corresponding HR recorded prior to- and including an RPE 13, and prior to- and including GET were extrapolated against submaximal $\dot{V}O_2$ to predicted HRmax according to the predictive equation: 206.9 – (0.67*age) as stated by Gellish et al. (2007), to obtain two further predictions of $\dot{V}O_2$max.

4.3.8 Statistical Analysis:

All individual coefficients of determination (R^2) calculated via the linear regression analyses were converted to Fisher Zr values to approximate the normality of the sampling distribution (Thomas & Nelson, 1996), and in order to obtain an average R^2 value for the whole sample.

A one sample t test was used to assess the difference between an RPE 13 and the average RPE reported at GET. Paired-samples t tests were also employed to assess mean differences in physical (WR) and physiological ($\dot{V}O_2$, HR, RER) variables corresponding to both an RPE 13 and GET.

a) Comparison of measured- and predicted $\dot{V}O_2max$:

A one-factor repeated measures ANOVA was used to compare the predictions of $\dot{V}O_2$max from an RPE 13 and GET with measured $\dot{V}O_2$max, and predictions of $\dot{V}O_2$max from submaximal HR equating to an RPE 13 and GET to measured $\dot{V}O_2$max. If data violated assumptions of sphericity using the Mauchly test, the Greenhouse-Geisser epsilon ($\hat{\varepsilon}$) correction factor was applied to improve the validity of the F ratio. Alpha was set at 0.05 and adjusted accordingly.

b) Measures of consistency between measured- and predicted $\dot{V}O_2max$:

Intraclass correlation coefficients (ICC) were calculated via the two-way mixed effects model to quantify the reproducibility between measured- and predicted $\dot{V}O_2$max. The agreement (bias & random error) between measured- and predicted $\dot{V}O_2$max was quantified using the 95 % limits of agreement (LoA) analysis (Bland & Altman, 1986).

c) Hierarchical regression analysis:

Hierarchical regression analysis, using measured $\dot{V}O_2$max as the dependent variable (DV), was used to assess the additive contribution of predicted $\dot{V}O_2$max from submaximal HR (at an RPE 13 & GET; independent variable: IV) on the predicted $\dot{V}O_2$max ascertained by the RPE (RPE_{19}, RPE_{20}; GET_{19}, GET_{20}; IV). By also assessing the additive contribution of the RPE on the relationship between predicted $\dot{V}O_2$max from submaximal HR (at an RPE 13 & GET), regression analysis allowed us to determine which variable (HR or RPE) accounted for the greatest variance, and as such the greatest additive contribution to the prediction of $\dot{V}O_2$max.

With the consideration that the measurement of $\dot{V}O_2$ is not always practicable, hierarchical regression analysis was additionally used to identify whether a collective model using age-predicted maximal HR ($HRmax_{pred}$) and WR elicited at an RPE 13 may provide an appropriate regression equation, following: $\dot{V}O_2max = b(HRmax_{pred}) + b(\text{WR at RPE 13}) + c$; to predict the $\dot{V}O_2$max of the low-fit women in this study from a submaximal exercise test. A paired-sample *t* test was subsequently conducted to compare any differences between measured $\dot{V}O_2$max and the $\dot{V}O_2$max predicted using the regression equation.

4.4 Results:

All physiological ($\dot{V}O_2$max, HRmax, RER) and perceptual (RPE) responses elicited at the termination of the exercise test are shown in Table 4.1.

Table 4.1. Maximal physiological (oxygen uptake: $\dot{V}O_2$; heart rate: HR; respiratory exchange ratio: RER), physical (work rate: WR) and perceptual (ratings of perceived exertion: RPE) responses at termination of the graded-exercise test.

	$\dot{V}O_2$max ml·kg^{-1}·min^{-1}	HRmax b·min^{-1}	RER	Maximal WR (W)	Terminal RPE
Women	30.9 ± 6.5	182 ± 7	1.16 ± 0.07	176.1 ± 33.6	19.1 ± 0.8

Individual R^2 values calculated using the submaximal $\dot{V}O_2$ and RPE data prior to- and including an RPE 13, and prior to- and including the GET produced average Fisher's *Zr* values of 2.03 and 2.18, respectively. This equated to average (transformed) values of R^2 = 0.97 and R^2 = 0.98, for RPE 13 and GET, respectively. Similarly, average Fisher's *Zr* values of 2.23 and 2.29, both equating to a correlation of R^2 = 0.98, were calculated between $\dot{V}O_2$ and HR at RPE 13 and GET, respectively. An average Fisher *Zr* value of 2.04 was also produced using individual coefficients of determination between measured $\dot{V}O_2$ and RPE responses recorded throughout the entire exhaustive exercise test (i.e. to $\dot{V}O_2$max / RPEpeak). This revealed an average coefficient of R^2 = 0.97 between $\dot{V}O_2$ and RPE to maximal exertion.

4.4.1 Comparison between GET and RPE 13:

A one sample *t* test revealed no significant difference between an RPE 13 and the average RPE reported at GET (12.1 ± 1.8; $P > 0.05$). Paired *t* tests, conducted to assess the difference between the physiological responses ($\dot{V}O_2$, HR, RER) and average WR attained at an RPE 13 to GET, revealed no significant differences in $\dot{V}O_2$ ($P >$ 0.05) between RPE 13 (19.4 ± 4.3 ml·kg^{-1}·min^{-1}) and GET (18.0 ± 4.8 ml·kg^{-1}·min^{-1}). Similarly, no significant differences ($P > 0.05$) were observed between HR at RPE 13 (140 ± 15 b·min^{-1}) and HR at GET (135 ± 18 b·min^{-1}). The RER between RPE 13 (1.00 ± 0.06) and GET (0.98 ± 0.06) was approaching significance ($t_{(10)}$ = 2.208, $P > 0.05$).

Furthermore, when participants reported an RPE 13, they were exercising at a significantly higher ($t_{(10)} = 3.235$, $P < 0.01$) average WR (99.3 ± 18.9 W) than at GET (80.5 ± 17.3 W).

4.4.2 Analysis of measured- and predicted $\dot{V}O_2$max:

One-factor repeated-measures ANOVA demonstrated no significant differences ($P > 0.05$) between measured $\dot{V}O_2$max (30.9 ± 6.5 ml·kg^{-1}·min^{-1}) and predicted $\dot{V}O_2$max from RPE_{19} (29.6 ± 6.8 ml·kg^{-1}·min^{-1}) or from GET_{19} (31.4 ± 7.7 ml·kg^{-1}·min^{-1}). Similarly, no significant differences ($P > 0.05$) were revealed between measured- and predicted $\dot{V}O_2$max from RPE_{20} (31.0 ± 7.5 ml·kg^{-1}·min^{-1}) or from GET_{20} (33.2 ± 8.3 ml·kg^{-1}·min^{-1}). In addition, no significant differences ($P > 0.05$) were observed between measured- and predicted $\dot{V}O_2$max from submaximal HR equating to an RPE 13 (31.0 ± 6.2 ml·kg^{-1}·min^{-1}), or GET (30.7 ± 8.5 ml·kg^{-1}·min^{-1}), respectively (Figure 4.1).

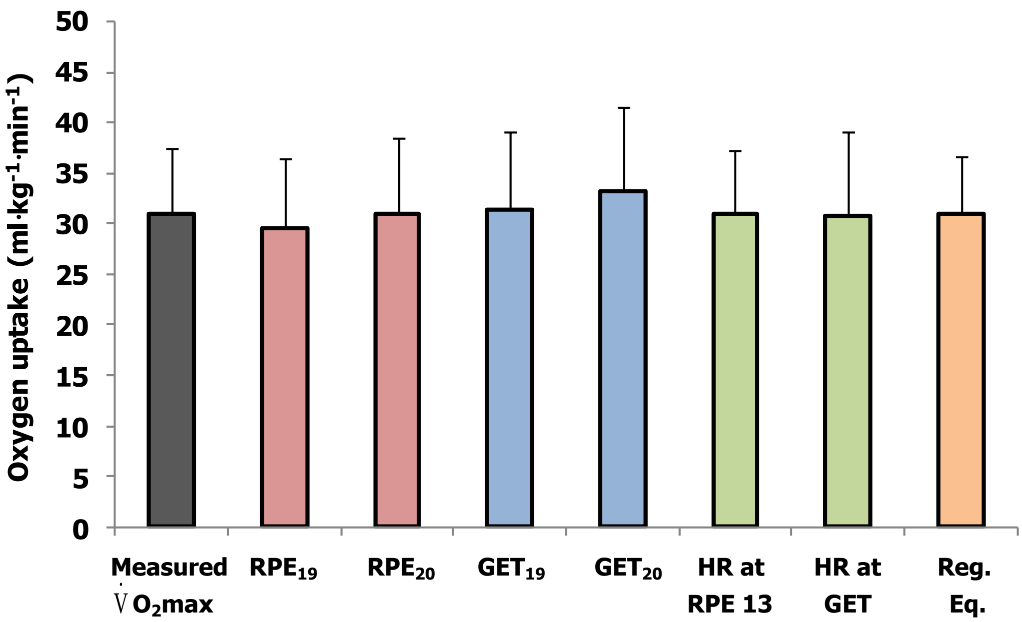

Figure 4.1. Comparison of measured- and predicted maximal oxygen uptake ($\dot{V}O_2$max; ml·kg^{-1}·min^{-1}) for each of the seven predictive methods, for women (regression equation: Reg. Eq.). Values are mean ± SD.

4.4.3 Reliability analyses of measured- and predicted $\dot{V}O_2max$:

Intraclass correlation coefficients (ICC: *R*) and 95 % LoA between measured- and predicted $\dot{V}O_2$max were much higher and narrower, respectively, for the predictions of $\dot{V}O_2$max from an RPE 13 than from either the GET or submaximal HR, as shown in Table 4.2.

Table 4.2. The Intraclass correlations (ICC; *R*) and 95 % limits of agreement (LoA) between measured- and predicted $\dot{V}O_2$max (ml·kg^{-1}·min^{-1}). The confidence intervals of the ICC are reported in parentheses.

	*RPE_{19}	*RPE_{20}	†GET_{19}	†GET_{20}	**HRmax (RPE 13)	**HR_{max} (GET)	††Regression Equation
ICC (*R*)	.96 (.84 - .99)	.94 (.76 - .98)	.53 (-.75 - .87)	.54 (-.71 – 88)	.85 (.43 - .96)	.69 (-.17 - .92)	.93 (.76 - .98)
95 % LoA (ml·kg^{-1}·min^{-1})	1.28 ± 5.27	-.41 ± 5.64	-.50 ± 15.88	-2.31 ± 16.48	-0.1 ± 9.1	0.2 ± 14.6	0.0 ± 6.0

* Predicted from an RPE 13

† Predicted from the RPE equating to gas exchange threshold (GET)

** Predicted from the heart rate at an RPE 13 and at GET, respectively

†† Predicted from the devised regression equation incorporating age-predicted heart rate maximum and work rate at an RPE 13

4.4.4 Hierarchical regression analysis:

The RPE accounted for 85 % ($P < 0.001$) and 79 % ($P < 0.001$) of the variance in measured $\dot{V}O_2$max (RPE_{19} and RPE_{20}, respectively) when analysed as the main IV. The additive contribution of the prediction of $\dot{V}O_2$max from HR at an RPE 13 (second IV) was a further 9 % ($P < 0.05$) and 11 % ($P < 0.05$) when extrapolated to RPE_{19} and RPE_{20}, respectively, which when combined accounted for 94 % and 91 % of the total variance in $\dot{V}O_2$max, respectively. Predictions of $\dot{V}O_2$max from HR at an RPE 13 (main IV) explained 54 % ($P < 0.05$) of the variance in measured $\dot{V}O_2$max (DV) with the additive contribution of RPE_{19} (second IV) accounting for a further 39 % ($P < 0.001$) or RPE_{20} (second IV), a further 36 % ($P < 0.05$). When predictions of $\dot{V}O_2$max from HR at

GET and the RPE at the GET (GET_{19}, GET_{20}) were analysed as either the main IV or secondary IV, neither significantly accounted for variance (≤ 29 %; $P > 0.05$) in measured $\dot{V}O_2$max.

Hierarchical regression analysis revealed that $HRmax_{pred}$ and WR at an RPE 13 accounted for a significant proportion (61 %, $P < 0.01$; and a further 17 %, $P < 0.05$, respectively) of the total variance (78 %) in measured $\dot{V}O_2$max. Accordingly, the corresponding regression equation developed for the prediction of $\dot{V}O_2$max was: $\dot{V}O_2max = .749\ (HRmax_{pred}) + .142\ (WR\ at\ RPE\ 13) - 122.37$. No significant differences ($P > 0.05$, SEE = 3.42 $ml \cdot kg^{-1} \cdot min^{-1}$) were observed between measured $\dot{V}O_2$max and the $\dot{V}O_2$max predicted from the regression equation (30.9 ± 5.76 $ml \cdot kg^{-1} \cdot min^{-1}$).

4.5 Discussion:

This study assessed the utility of a ramp-incremental protocol in facilitating accurate estimates of $\dot{V}O_2$max from submaximal $\dot{V}O_2$ corresponding to the gaseous exchange threshold and an RPE 13 in healthy, low-fit women, during a single exercise bout on a cycle ergometer. The strong relationship between the Borg (1998) 6-20 RPE scale and physiological criteria was confirmed in this study, as demonstrated by a commensurate rise in the RPE and $\dot{V}O_2$ that produced a high coefficient of determination (R^2 = 0.97) across the duration of the exhaustive exercise test. Strong coefficients of determination were also observed between the RPE and $\dot{V}O_2$ during the lower workloads, up to- and including both an RPE 13 (R^2 = 0.97) and GET (R^2 = 0.98). This is contrary to previous research that suggests the RPE to be more strongly correlated with physiological variables at higher intensities of exercise (Eston & Williams, 1988; Faulkner et al., 2007). A strong linear relationship (R^2 = 0.98) between the $\dot{V}O_2$ and HR response to increasing exercise intensity was similarly observed prior to- and including both an RPE 13 and GET.

4.5.1 Physiological cost of exercising at the gas exchange threshold and an RPE 13:

A single, low to moderate intensity estimation protocol, which facilitates accurate predictions of $\dot{V}O_2$max, has the potential to be an appropriate means of stress testing certain low-fit or clinical populations. Furthermore, when prescribing exercise to healthy low-fit populations, exercise of a lower intensity may be more appropriate as such groups are more likely to be negatively affected by the demand of high intensity exercise (Hardy & Rejeski, 1989; Parfitt et al., 1996). On the basis of anecdotal evidence and past research (study 1), it was postulated that in most cases GET would occur prior to an RPE 13 being reported. As such, if accurate estimates of $\dot{V}O_2$max could be obtained using the GET, it would have the advantage of further reducing the duration of a stress test. It is notable in this study that on average, GET was observed approximately 47-s prior to participants reporting an RPE 13 (5-min 45-s cf. 6-min 32-s, respectively), and that the average workload attained at GET was statistically lower than the corresponding workload at an RPE 13. However, no statistical differences were apparent between the perceptual responses or the physiological costs of the exercise ($\dot{V}O_2$, HR, & RER) between conditions (GET cf. RPE 13). Indeed for the participants in this study, GET occurred at approximately 59 % of their $\dot{V}O_2$max, in accordance with Jones and Poole (2005), whereas at an RPE 13, participants attained approximately 64 % of their $\dot{V}O_2$max, which is similar to the observations of previous research (study 1; Faulkner et al., 2007).

The ACSM (2010) recommends 40 to 85 % of oxygen uptake reserve ($\dot{V}O_2$R) or 50 to 90 % HRmax as a suitable exercise intensity range to enhance cardiorespiratory fitness. At RPE 13, the mean $\dot{V}O_2$ consumption of all participants in the current study was 19.4 ± 4.3 ml·kg^{-1}·min^{-1}. This accords with the guidelines of the ACSM (2010) as it equated to 60 % of $\dot{V}O_2R$, or 5.5 METS, which is similarly in the recommended range for moderate daily activity (3-6 METS). Comparable findings were also observed for heart rate, with participants attaining approximately 74 % and 77 % of their HRmax at GET and an RPE 13, respectively. Furthermore, the average duration of the test (6-min 32-s), from the onset of exercise to the participant reporting an RPE 13 was comparable to the findings of study 1. In the latter study, the time taken for women to report an RPE 13 during a GXT to $\dot{V}O_2$max was approximately 6 min (9 min for men). Interestingly however, predictions of $\dot{V}O_2$max in the current study (RPE_{19} and RPE_{20}) are relatively more accurate than the predictions from an RPE 13 extrapolated to either an RPE_{19} or RPE_{20} in the preceding study (study 1).

4.5.2 Comparison of $\dot{V}O_2$max predictions using theoretical maximal- and terminal RPE:

Previous research (Faulkner et al., 2007) observed that predictions of $\dot{V}O_2$max from lower perceptual ranges (i.e. 9-13 or 9-15) are more accurate when extrapolated to theoretical maximal RPE (RPE_{20}) rather than the peak terminal RPE (RPE_{19}) consistently reported at volitional exhaustion (Eston et al., 2007; Faulkner et al., 2007; Kay et al., 2001; St Clair Gibson et al., 1999). However, this study demonstrated equivalently accurate estimates of $\dot{V}O_2$max when extrapolating from an RPE 13 to either an RPE_{19} or RPE_{20}. Furthermore, no statistical differences were noted between measured- and predicted $\dot{V}O_2$max from GET when extrapolated to an RPE_{19} or RPE_{20}. As such, this study further demonstrates the utility of submaximal ratings of perceived exertion for providing an appropriate indication of an individual’s maximal aerobic capacity. Moreover, as there were no differences between measured- and predicted $\dot{V}O_2$max from heart rate at GET or RPE 13 when extrapolated to age-predicted maximal heart rate (Gellish et al., 2007), we can also infer that heart rate was an accurate indicator of maximal aerobic capacity in the low-fit women in this study.

4.5.3 Evaluation of the measures of consistency in predictions of $\dot{V}O_2max$:

Despite no apparent differences between measured- and predicted $\dot{V}O_2$max, measures of agreement and consistency indicate that estimates of $\dot{V}O_2$max obtained from an RPE 13 may be more accurate than those from either the GET or submaximal heart rate extrapolated to age-predicted HRmax. In this regard, the predictions from an RPE 13 revealed narrower LoA and higher ICCs (LoA: 1.28 ± 5.27 & -0.41 ± 5.64 ml·kg^{-1}·min^{-1}; R^2 = 0.96 & 0.94, for RPE_{19} & RPE_{20}, respectively) than the predictions from the GET (LoA: -0.50 ± 15.88 & -2.31 ± 16.48 ml·kg^{-1}·min^{-1}; R^2 = 0.53 & 0.54, for GET_{19} & GET_{20}, respectively), or HR at either RPE 13 (LoA: -0.1 ± 9.1 ml·kg^{-1}·min^{-1}; R^2 = 0.85) or GET (LoA: 0.2 ± 14.6 ml·kg^{-1}·min^{-1}; R^2 = 0.69) when extrapolated to age-predicted maximal heart rate.

It is interesting to note that when two participants are excluded from the reliability analyses, due to the considerable variability in their $\dot{V}O_2$ in relation to their RPE responses, the LoA between measured- and predicted $\dot{V}O_2$max for the remaining participants in this study substantially improve to 2.78 ± 6.84 and 1.14 ± 6.84, and the ICCs increase to R = 0.90 for both GET_{19} and GET_{20}. It is plausible that the large discrepancy between predictions from GET and an RPE 13 for these two participants, despite the relative similarities in terms of physiological cost between the two conditions, may in part be the result of methodological error. The process of extrapolating submaximal $\dot{V}O_2$ values from estimates of exertion via linear regression analysis is a relatively novel but generally reliable means of obtaining acceptable predictions of $\dot{V}O_2$max (study 1; Davies et al., 2008; Eston et al., 2005, 2006, 2008; Faulkner et al., 2007, 2008). However, the precision of the method is highly dependent upon an individuals' ability to *accurately* rate his or her perception of exertion. Thus, if an individual *underestimates* their perception of exertion during the lower work rates (i.e. below GET), linear extrapolation will exacerbate this error, ultimately resulting in an *overestimation* of $\dot{V}O_2$max. Furthermore, as GET was identified retrospectively, a corresponding RPE value was calculated via the same linear regression analysis technique. The subsequent use of this calculated RPE value in the estimation of $\dot{V}O_2$max from the GET may, therefore, have contained inherent error and have resulted in a less accurate prediction.

It is of further interest to consider the appropriateness of the LoA between measured- and predicted $\dot{V}O_2$max in this study when inferring the utility of the RPE during submaximal stress test procedures. For the women in this study, the identified LoA mean that (in worst case scenario) a predicted value might be 6.6 ml·kg^{-1}·min^{-1} above- or 4.0 ml·kg^{-1}·min^{-1} below the measured value when extrapolating submaximal $\dot{V}O_2$ up to- and including RPE 13 to RPE$_{19}$, or 5.2 ml·kg^{-1}·min^{-1} above- or 6.1 ml·kg^{-1}·min^{-1} below the measured value when extrapolating to RPE$_{20}$. Alternatively, this equates to a 21 % or 20 % margin of error between measured- and predicted $\dot{V}O_2$max (for RPE$_{19}$ and RPE$_{20}$, respectively).

It is interesting to note how these values compare with many recent studies in this area which have employed both perceptually-regulated and estimation procedures. Faulkner et al. (2007) observed a 35 % margin of error in the prediction of $\dot{V}O_2$max from an RPE range 9-13 during a perceptually-regulated GXT, which is wider than that observed in the present study. It is notable that improvements in the agreement between measured- and predicted $\dot{V}O_2$max have been demonstrated when extrapolating from a higher perceptual range, and following a period of familiarisation. In the original study by Eston et al. (2005), the error between measured- and predicted $\dot{V}O_2$max from an RPE range 9-15 reduced by 8 % (from 26 % to 18 %) over the course of three perceptually-regulated exercise tests. Similar improvements have also been observed in Eston et al. (2006, 2008), Faulkner et al. (2007), and Morris et al. (2009) following a period of familiarisation. With regards to estimation procedures, research has typically shown between 27 – 29 % error in the prediction of $\dot{V}O_2$max from perceptual ratings reported prior to- and including either an RPE 13 or RPE 15 (study 1; Coquart et al., 2009b; Faulkner & Eston, 2007). It would be prudent to acknowledge that the worst case error of 21 % and 20 % in the current study still represents significant variability in estimates of $\dot{V}O_2$max. However, when considering the findings from the aforementioned studies, such a margin of error may actually be considered quite favourable. The only significant distinction between the protocol adopted in the current study and that employed in the previous study (study 1) or by Faulkner and Eston (2007) was the application of a continuous increase in work rate (ramp-incremental protocol) as opposed to an incremental step-increase in work rate. As such, it is feasible to consider that the continuous change in work rate may have induced a more frequent appraisal of the feelings of exertion, which in turn may have facilitated more accurate estimates of $\dot{V}O_2$max. Furthermore, the continuous work rate employed in the current study is in keeping with the ACSM (2010), which advocates the use of 15 W increases in work rate per minute during cycle ergometry when exercise testing deconditioned individuals or patients with cardiovascular or pulmonary disease.

4.5.4 Efficacy of submaximal ratings of perceived exertion, heart rate and work rate for exercise prescription:

The hierarchical regression analyses revealed that the combined predictions of $\dot{V}O_2$max from heart rate at an RPE 13 and from the RPE extrapolated to an RPE_{19} accounted for the greatest of the variance in measured $\dot{V}O_2$max (94 %). Furthermore, the RPE alone accounted for 85 % of the overall variance, compared to 54 % explained by heart rate alone. Such findings are important when considering the potential clinical application of the RPE, as these results imply that clinicians may benefit highly from employing the RPE as an adjunct to heart rate during exercise stress testing with low-fit individuals.

Given that the measurement of $\dot{V}O_2$ may be unavailable or not feasible in some situations, it is plausible that the submaximal work rate which equates to an RPE 13 may be used as a substitute for the corresponding submaximal measurement of $\dot{V}O_2$, for the prediction of an individual's maximal functional capacity. In this regard, hierarchical regression analysis demonstrated that a combination of $HRmax_{pred}$ and the WR at RPE 13 accounted for 78 % of the overall variance in $\dot{V}O_2$max. Although a corresponding regression equation was produced from this analysis, it is pertinent to recognise that a larger sample size is necessary to enable a more rigorous and appropriate regression equation to be developed for use with a population of low-fit women. Nevertheless, similar regression equations have been developed and employed with relative success in order to predict an individual's maximal tolerance for exercise. Johnson and Prins (1991) demonstrated that a multiple regression equation, which incorporates the submaximal heart rate equating to an RPE 15, may better predict the heart rate maximum of healthy, relatively-fit men and women than the commonly employed equation of 220 – age. The results of the current study are encouraging, as the regression equation in this study accounted for a relatively greater amount of variance in $\dot{V}O_2$max than the regression equation developed by Johnson and Prins in the prediction of heart rate maximum (78 % cf. 58 %, respectively). Moreover, the current regression equation was determined using less 'factors', and from a lower exercise intensity (RPE 13). Thus, further research into the efficacy of such regression equations for the purpose of exercise prescription with low-fit individuals may be warranted.

4.6 Conclusion:

This study has demonstrated that accurate predictions of $\dot{V}O_2$max may be obtained from a single, estimation exercise test to a moderate intensity (RPE 13) in low-fit women. Moreover, the findings suggest that more accurate estimates of perceived exertion and consequently more accurate predictions of $\dot{V}O_2$max may be elicited from a continuous exercise test rather than a step-incremental test. Prediction of $\dot{V}O_2$max from the gas exchange threshold is not recommended due to the large potential for inaccuracies. Extrapolation of submaximal heart rate (equating an RPE 13) to age-predicted HRmax (Gellish et al., 2007) may also provide accurate predictions of $\dot{V}O_2$max in low-fit women. Clinicians may be advised that the RPE may be a valuable tool that can be easily employed as an adjunct to heart rate, and may provide supplementary clinical information that is superior to using heart rate alone. A ramp-incremental protocol may reduce the duration, and thus the associated cost and motivational effort involved in an exercise stress test.

Chapter 5

Study 3

The perceptual response to exercise of progressively increasing intensity in children aged 7 – 8 years: validation of a pictorial curvilinear ratings of perceived exertion scale

This study has contributed to the following publication and presentations:

Publication:

Eston, R.G., Lambrick, D.M., & Rowlands, A.V. (2009). The perceptual response to exercise of progressively increasing intensity in children aged 7 – 8 years: validation of a pictorial curvilinear ratings of perceived exertion scale. *Psychophysiology*, 46, 843-851.

Oral presentations:

Lambrick, D.M., Eston, R.G., & Rowlands, A.V. (2009). The perceptual response to exercise of progressively increasing intensity in children aged 7 – 8 years: validation of a pictorial curvilinear ratings of perceived exertion scale. The 13th Annual Congress of the European College of Sport Science (Estoril, Portugal, 10th July, 2008).

Lambrick, D.M., Eston, R.G., & Rowlands, A.V. (2009). The perceptual response to exercise of progressively increasing intensity in children aged 7 – 8 years: validation of a pictorial curvilinear ratings of perceived exertion scale. The 2nd Annual Postgraduate Conference (Exeter, UK, 6th June, 2008).

5.1 Abstract:

This study assessed the validity of the Eston-Parfitt (E-P) curvilinear Ratings of Perceived Exertion (RPE) scale and a novel marble quantity task to provide estimates of perceived exertion during cycle ergometry. Fifteen children aged 7 – 8 years performed a discontinuous incremental graded-exercise test, and reported exertional ratings at the end of each minute. Significant increases in physiological and perceptual data were observed with increasing work rate. Strong linear (R^2 = 0.93) and curvilinear (R^2 = 0.94) relationships between RPE from the E-P scale and work rate confirmed the robustness of the E-P scale. The relationship between the marble task and work rate was curvilinear (mean R^2 = 0.94), supporting the theoretical justification for the E-P scale. Valid exertional ratings may be obtained using the E-P scale with young children. The novel marble quantity task offers an alternative method of deriving perceived exertion responses in children.

5.2. Introduction:

Most research on perceived exertion in children has focused on the suitability of methods of assessing exercise effort, with a great deal of attention paid in particular, to the appropriateness of the perceptual scales employed (Barkley & Roemmich, 2008; Eston & Parfitt, 2007; Lamb et al., 2008; Roemmich et al., 2006). As consideration of age and the cognitive developmental level of the child are fundamental for assessing perceived exertion in children, a number of child-specific ratings scales have been developed in the last 20 years, as discussed in the review of literature.

5.2.1. Development of linear paediatric RPE scales:

The publication of the Children’s Effort Rating Table (CERT; Eston et al., 1994; Williams et al., 1994), proposed three years earlier (Williams et al., 1991), was considered an important advancement in the study of effort perception in children (Bar-

Or & Rowland, 2004). This scale was the forerunner to several 'developmentally-appropriate' paediatric RPE scales, including the CALER (Eston et al., 2000), BABE (Parfitt et al., 2007), PCERT (Yelling et al., 2002) and OMNI scales (Robertson et al., 2000a), among others (Figure 5.1). The CERT was founded on the basis of a linear relation between RPE and heart rate (HR; Eston et al., 1994; Williams et al., 1994), similar to the original design of the Borg 6-20 scale (Borg, 1998). Indeed, all currently validated pictorial child-specific rating scales depict a child at varying stages of exertion on either a horizontal line or a linearly increasing gradient to express the relationship between a child's perception of exertion and increasing exercise intensity.

5.2.2. Validity of linear paediatric RPE scales:

The validity of each of the aforementioned child-specific scales has been assessed in relation to physiological variables, such as HR and the rate at which oxygen is consumed ($\dot{V}O_2$), that rise commensurately with increases in exercise intensity. The relationships between perceived exertion and various cardiorespiratory measures are comparable to those observed when employing the Borg 6-20 scale with adults, and indicate how closely perceived exertion in children matches the physiological changes throughout exercise.

In this regard, a strong correlation has been noted for the CALER with HR (r = 0.92) and $\dot{V}O_2$ (r = 0.88), during cycle ergometry exercise (Barkley & Roemmich, 2008). The concurrent validity of the PCERT has been confirmed by Roemmich et al., (2006), who reported strong linear relationships with HR (r = 0.86 & r = 0.92 for boys & girls, respectively) and $\dot{V}O_2$ (r = 0.86 & r = 0.94 for boys & girls, respectively) during treadmill exercise. Although more variable, differing OMNI scales of perceived exertion have shown to correlate with HR from r = 0.26 to r = 0.93 (Barkley &

Roemmich, 2008; Utter et al., 2002b), and with $\dot{V}O_2$ from r = 0.32 to r = 0.94 (Robertson et al., 2000a; Utter et al., 2002b) across various exercise modalities.

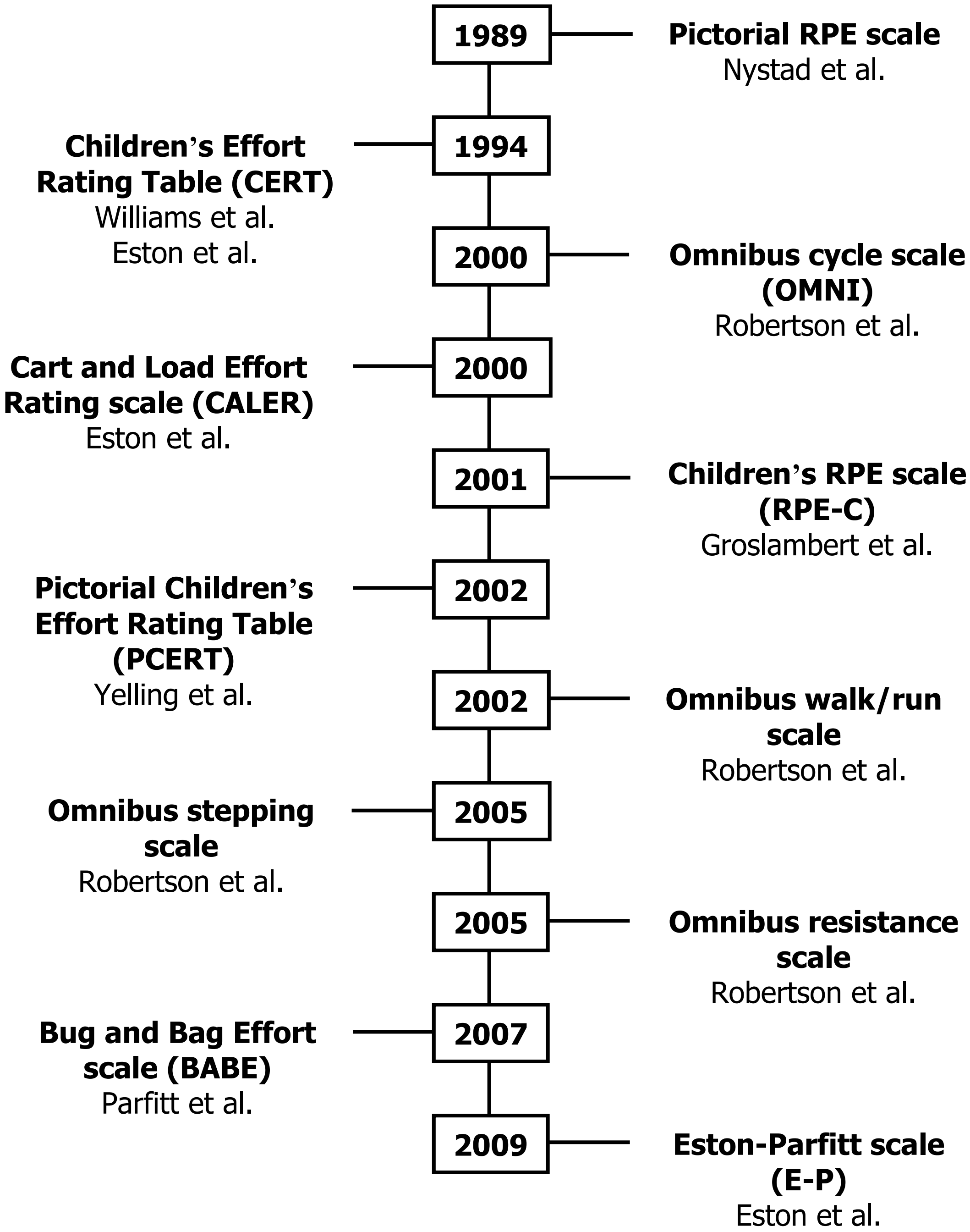

Figure 5.1. Timeline depicting the development of paediatric ratings scales.

5.2.3. Rationale for a curvilinear paediatric RPE scale:

It is feasible to consider that ventilation ($\dot{V}_E$) may be a mediating factor in respiratory-metabolic signals of exertion in children, such as in adults, particularly at higher intensities of exercise (Noble & Robertson, 1996). At lower workloads, $\dot{V}_E$ tracks metabolic demand, or $\dot{V}O_2$, in a linear fashion (Rowland, 2005). As work load increases, above approximately 60 % $\dot{V}O_2$max, $\dot{V}_E$ begins to rise at an accelerated rate to account for metabolic acidosis and bicarbonate buffering of lactic acid (Orenstein, 1993; Rowland, 2005). It has been suggested that between 45 – 70 % $\dot{V}O_2$max, $\dot{V}_E$ provides strong sensory signals of exertion (Robertson, 1982). Indeed in adults, it has been proposed that ventilatory function and discomfort may be the only central signals of exertion that are consciously monitored, whereas HR does not appear to be associated with strong sensations of effort (Robertson, 1982).

If $\dot{V}_E$ is a strong exertional mediator and it increases according to a positive growth function above work rates of 60 % $\dot{V}O_2$max, it follows that the RPE will also increase in a positively accelerating fashion at the higher exercise intensities. This, in conjunction with the postulation that children will readily conceive that the *steeper the hill, the harder it is to ascend*, has led to the development of a curvilinear pictorial RPE scale specifically intended to assess the perceived exertion of young children (Eston & Parfitt, 2007; Faulkner & Eston, 2008).

5.2.4. The Eston-Parfitt (E-P) scale of perceived exertion:

As detailed in chapter 2, the Eston-Parfitt (E-P) scale (Figure 2.8) utilises a similar numerical range as other validated paediatric rating scales, and incorporates verbal properties of the CERT. Yet the distinguishing feature of the E-P scale is its concave slope that has a progressively increasing gradient at the higher intensities to denote the curvilinear relationship between the RPE and increasing work. The inspiration for shading the area under the curve from light to dark red from left to right, respectively, stemmed originally from a suggestion by Gunnar Borg (Eston, 2009b).

Data from a recent study by Barkley and Roemmich (2008) on 9 – 10 year-old children have indicated that a scale which depicts a curvilinear rise in the RPE response may be warranted. They observed that children indicated RPE scores that were 75 (± 20) % and 74 (± 19) % of the numerical range for CALER and OMNI, respectively, at a corresponding HR response of 94.5 % of the age-predicted maximal HR, during the final stage of a progressive maximal cycle ergometer test. They speculated that if children were to indicate a maximal score on the RPE scale at predicted maximum HR or $\dot{V}O_2$, then the rise in RPE would have to increase at a faster rate than had occurred at the lower workloads.

Encouraging pilot data using the E-P scale in the production mode has previously been reported (Eston & Parfitt, 2007). In their study, healthy boys and girls (aged 8 – 11 years) were required to bench step continuously for 3-min at self-regulated exercise intensities corresponding to RPE levels 2, 5 and 8. High intraclass-correlations of R = 0.71, 0.75 and 0.76 were reported between HR and RPE levels 2, 5 and 8, respectively, across 6-experimental trials. However, no further validation studies have been conducted using the curvilinear E-P scale.

5.2.5. Purpose & hypotheses:

The purpose of this study was to assess the validity of the E-P scale during an incremental graded-exercise test (GXT) on a cycle ergometer against continual measurement of HR, $\dot{V}O_2$, $\dot{V}_E$ and work rate (WR) in healthy children, aged 7 – 8 years. To further investigate the notion that a child's effort perception increases curvilinearly with linear increases in work rate, a novel 'psycho-physical' marble dropping task was implemented. Moreover, it was of interest to assess to what extent select physiological variables mediate the perceptual response during cycle ergometry exercise in young children. We hypothesised that children would readily understand and utilise the E-P scale and the marble task to provide valid estimates of their perception of exertion in relation to increases in exercise intensity. We also hypothesised that the number of marbles taken from one container and placed into another with increasing exercise intensity would increase disproportionately in relation to HR, $\dot{V}O_2$, and WR. Furthermore, that ventilation would exert the strongest influence over the RPE response during cycling exercise.

5.3. Method

5.3.1 Participants:

Fifteen healthy children (six boys; age: 7.5 ± 0.5 y; height: 1.29 ± 0.03 m; body mass: 25.8 ± 2.5 kg, and nine girls; age: 7.6 ± 0.5 y; height: 1.29 ± 0.04 m; body mass: 27.3 ± 2.1 kg) were recruited for this study (see Appendices 1c & 1d) from a local independent school in the Exeter area. Parents / guardians provided written informed consent (Appendix 2c) to their child’s participation, and each participant signed an informed assent form (Appendix 2d) prior to the commencement of the study. All participants were asymptomatic of illness or disease and free from any acute or chronic injury. This information was gathered by means of a ‘Health Screening’ form (Appendix 9), completed by parents / guardians on behalf of each child. The study was approved by the Ethics Committee of the School of Sport and Health Sciences at the University of Exeter.

5.3.2. Procedures:

Height and body mass (SECA, Hamburg, Germany) were recorded for each participant prior to the exercise test. Each participant then performed a single graded exercise test (GXT) to volitional exhaustion on an electronically-braked cycle ergometer (Lode Excalibur Sport V2, Lode BV, Groningen, The Netherlands). Seat height, handle bar and pedal position were adjusted accordingly for each participant. Resistance on the cycle ergometer was manipulated automatically via the Lode workload programmer, accurate to ±1 W, which was linked to the Cortex software (Cortex Metalyzer II, Biophysik, Leipzig, Germany) that utilised a previously programmed exercise protocol. All information screens displaying power output or any other physiological data ($\dot{V}O_2$, HR, $\dot{V}_E$) were masked from the participant during the test. Revolutions per minute ($rev{\cdot}min^{-1}$) were visible to the participant on the Lode display screen, and it was expressed that the desired pedal cadence of 70 $rev{\cdot}min^{-1}$ was to be maintained throughout the test. This was to reduce the potential effect of low pedal cadence (< 60 $rev{\cdot}min^{-1}$) and therefore greater resistance per pedal revolution, on the overall sensation of exertion (Jameson & Ring, 2000). Respiratory gas analysis ($\dot{V}O_2$, $\dot{V}_E$, RER) was performed continuously using breath-by-breath sampling (Cortex Metalyzer II, Biophysik, Leipzig, Germany). The system was calibrated prior to each test following the manufacturers guidelines, with ambient air measurements calibrated against known concentrations of gas, and volume calibrations performed using a 3-L syringe (Hans Rudolph Inc., Kansas City, USA). A large paediatric facemask (Hans Rudolph Inc., Kansas City, USA) was used to collect expired air, and assisted in allowing participants to verbally communicate with the experimenters. Heart rate was recorded throughout the test using a paediatric wireless chest strap telemetry system (Wearlink+, Polar Electro Oy, Kempele, Finland).

Each child had been given a copy of the E-P scale to take home several weeks in advance of the start of the study, at which time they also received a full verbal explanation as to how to use the scale. No active familiarisation with the scale was given prior to the test. However, the children were given further standardised instructions on how to implement the scale during their test session. They were also guided through memory-recall anchoring techniques using maximal values of the E-P scale (RPE 10) as an upper reference point to help gauge their perceptual responses. In this study, the scale was mounted on a wooden board that contained a sliding marker that could be used by the participant to select an RPE rating. The scale remained in full view of the child for the duration of the test. The children were similarly given standardised instructions (including memory-recall anchoring techniques) on how to perform the marble task, which involved grasping a preferred number of marbles (out of a possible 50) from a container and placing them into another container, according to their current perception of effort. The harder the exercise felt to the participant, the more marbles they collected from the container, and vice versa. The marble task uses interval scaling and was anchored so that the maximum number (50) equated to the same level of exertion as the maximum number on the E-P scale (10; i.e., ‘So hard I am going to stop’). However, values between 0 – 50 were not specifically correlated in any way to the numerical range or verbal descriptors of the E-P scale (i.e., 25 marbles did not equate to 5 or ‘somewhat hard’ on the E-P scale). The marble task was therefore designed and employed alongside the E-P scale under the assertion that children would freely allocate a number- or amount of marbles (between 0 & 50) to their perceived level of exertion. Accordingly, it was postulated that by using this task, both linear- and curvilinear perceived exertion responses may become apparent in relation to increasing work rate.

The order in which each method was implemented was randomised between participants but remained consistent during each test. Any queries regarding the application of the scale or the procedure for the marble task were resolved before the start of the exercise test.

5.3.3. E-P scale instructions:

The instructions for both the E-P scale (modified from Robertson et al., 2000a) and the marble quantity task were as follows:

"Whilst you are exercising on the bicycle, we would like you to use this scale to tell us how your body feels. You can point to a number or slide the marker along the scale to tell us how you feel. Please look at the person on the left (point to the left pictorial). If you feel like this person whilst riding the bicycle, it will feel *very, very easy* to you. Please look at the person on the right (point to the right pictorial). If you feel like this person whilst riding the bicycle, then you will feel that it is '*so hard I am going to stop'*. If you feel somewhere in between *very, very easy* (0) and *so hard I am going to stop* (10) then point- or slide the marker to a number between 0 and 10.

"We would also like you to use these marbles to tell us how you feel whilst you are cycling. The harder the exercise feels to you, the more marbles you take from this container and place into the empty container. If you feel that the exercise is *very, very easy* to you, then you should take a few marbles and place them into the empty container. If the exercise feels *so hard that you are going to stop*, then you may place lots of marbles into the empty container. If you feel somewhere in between *very, very easy* and *so hard I am going to stop*, then you may choose any number of marbles to place into the empty container.

"We would like you to *really* think about how your whole body feels when you are riding the bicycle – how your legs feel and how your breathing (chest) feels. Try to answer as honestly as possible. There are no right or wrong answers".

5.3.4. Graded exercise test (GXT) to $\dot{V}O_2peak$:

All participants completed a 3-min warm-up on the cycle ergometer at a resistance of 15 W, followed by a 2-min rest where the procedural instructions were briefly repeated. A discontinuous GXT protocol was then applied which commenced at 10 W for 1-min, followed by an intervening 1-min period of unloaded cycling. The WR from the previous active bout of exercise was then increased by 10 W for 1-min, and this procedure was repeated until the participant attained maximal oxygen uptake ($\dot{V}O_2$peak). During the final 15-s of each minute of loaded cycling throughout the exercise test, participants were asked to report their perception of exertion using two methods (Figure 5.2). The E-P scale was placed in front of the participant whilst cycling; the participant then moved the sliding marker along the numerical scale to the number that satisfied their level of exertion at that specific exercise intensity, or pointed to a corresponding place on the slope. If the participant had pointed to a place on the slope, a perpendicular line was drawn down from this point to obtain a corresponding numerical value. The equivalent number was recorded and/or the marker was returned to the starting position on the scale (zero).

Figure 5.2. Participant completing the discontinuous, graded-exercise test to exhaustion, on a cycle ergometer; both rating methods (E-P scale & marbles task) are visible.

Immediately after (or prior to the E-P scale being employed) participants selected any number of marbles (out of a possible 50) from a container and placed them into an identical container, adjacent to the first. The number of marbles placed into the adjacent container was recorded, after which, the marbles were returned to the original container (Figure 5.3). The question "*how hard does the exercise feel to you?*" was asked prior to each method being implemented.

Figure 5.3. Participant rating his perception of exertion using the marble task, during the graded-exercise test to exhaustion on a motorised treadmill.

Criteria for terminating the exercise test included exhaustion, in association with HR ≥ 195 b·min^{-1}; respiratory exchange ratio (RER) ≥ 1.02; an evident plateau or peak in $\dot{V}O_2$, or < 2.1 ml·kg^{-1}·min^{-1} increase in $\dot{V}O_2$ in the final stage of exercise; pedal cadence < 70 rev·min^{-1} for a period greater than 5-s (Rowland, 1996). At the end of the exercise test, participants cycled against a light resistance to aid recovery.

5.3.5. Data Analysis:

Physiological ($\dot{V}O_2$, HR, $\dot{V}_E$) and perceptual (E-P scale, marbles) data, recorded in the final 15-s of each active exercise bout, were collated and used in the subsequent analyses.

a) Assessing the nature (curvilinear / linear) of the perceptual response:

To test the curvilinear properties of the E-P scale and the marble task, individual regression analyses, using Microsoft Office Excel software (Microsoft Office Excel, 2003, version 11), were conducted using both linear and curvilinear ('exponential') lines of best fit on the perceptual data (dependent variable) in relation to WR (independent variable). Individual coefficients of determination (R^2) were calculated across relative maximal work rates (i.e. 10 – 120 W). To approximate the normality of the sampling distribution, all individual R^2 values were converted into *Zr* values using Fisher's *Zr* transformation. A mean *Zr* value was then calculated and re-converted into a mean R^2 for all participants in this study. An identical procedure was employed between the RPE data measured by the E-P scale and the marble task with $\dot{V}O_2$.

b) Assessing the physiological and perceptual response to increasing exercise intensity:

Due to the nature of the cycling protocol implementing fixed, absolute increments in WR, variable maximal WR were attained by participants in this study (70 – 120 W). As such, repeated-measures ANOVA assessed the change in $\dot{V}O_2$, HR, $\dot{V}_E$, RPE from the E-P scale and marble response with increasing exercise intensity across the first seven stages of the exercise test. If data violated assumptions of sphericity using the Mauchly test, the Greenhouse-Geisser epsilon (ε) correction factor was applied to improve the validity of the *F* ratio. Furthermore, where significant differences were observed, paired samples *t* tests with Bonferroni adjustment were employed to investigate where the differences lay. To account for the decreasing number of participants at the higher intensities of exercise, the remaining data from stages 8 – 12 (80 – 120 W) were subsequently analysed using a series of paired *t* tests.

c) Regression analysis to assess physiological responses in relation to increasing work rate:

Due to the decreasing number of participants attaining the higher exercise intensities, it is plausible that the preceding methods for assessing the physiological and perceptual response to increasing work rate may be subject to a decrease in statistical power. Accordingly, this may confound the interpretation of the analyses. For the purpose of methodological rigor, therefore, individual regression analyses were also employed to assess the relationship between physiological responses ($\dot{V}O_2$, HR, $\dot{V}_E$; dependent variable) and increasing WR (independent variable), across the full duration of the exercise test. Individual coefficients of determination (R^2) were subsequently calculated using Fisher's *Zr* transformation across relative maximal work rates, to approximate the normality of the sampling distribution (Thomas & Nelson, 1996) and in order to obtain an average R^2 for the whole participant sample (n = 15).

d) Assessing the relationship between potential mediators of exertional responses:

Individual regression analyses (using both linear and curvilinear lines of 'best-fit'; with Fisher's *Zr* transformation) were conducted to assess the strength of the relationships between potential physiological mediators of perceptual responses ($\dot{V}O_2$, HR, $\dot{V}_E$) and the RPE (E-P scale and marbles). Paired *t* tests, with Bonferroni adjustment ($P < 0.008$), were subsequently performed for each physiological variable in relation to the E-P scale and in relation to the marble task in order to obtain the six 'best-fit' relationships (e.g. whether a linear or curvilinear model best described the relationship between $\dot{V}O_2$ & RPE; noted as a significantly higher R^2).

e) Further assessment of physiological mediators using hierarchical regression analysis:

Although regression analysis provides pertinent information regarding the relationship between two variables, it does not explain any variance in the outcome. As such, hierarchical regression analysis was utilised to assess the additive contribution of $\dot{V}O_2$, HR or $\dot{V}_E$ (IV) to account for the variance in the RPE response using both the E-P scale (DV) and marble task (DV), throughout the cycling GXT. By alternating the order in which each IV was inserted into the regression analysis, it was possible to determine which variable ($\dot{V}O_2$, HR or $\dot{V}_E$) accounted for the greatest variance in the perceptual response.

f) Calculation of exponents of the perceptual relationship with increasing work rate:

To further examine the nature of the perceptual response to cycling exercise of increasing intensity in 7 – 8 year-old children, natural logarithmic values (exponents) were calculated for the relationship between the RPE (E-P scale; marbles) and WR for each participant in this study. The collated exponents were subsequently averaged to obtain a mean value that reflected the nature of the relationship between these two variables, in this population.

g) Select analyses to ensure consistency of the findings:

To investigate the consistency of pedal cadence throughout exercise tests, particularly during the period of rating perceived exertion (during the final 15-s of each active bout of exercise), a coefficient of variation analysis was performed on the pedal revolution data (rev·min^{-1}). A paired *t* test was also utilised between the two randomly allocated groups of participants who either rated their perceived exertion using the E-P scale first or the marble task first. This was to investigate whether the visibility of the E-P scale for the duration of the test had marked influence on the exertional ratings provided by the participants when using the marble task.

Alpha was set at 0.05, and adjusted accordingly. All analyses were performed using the statistical package SPSS for Windows, version 13.0.

5.4. Results:

The maximal physiological and perceptual responses recorded at termination of the cycling GXT were: (mean ± SD); $\dot{V}O_2$: 53.5 ± 9.4 ml·kg^{-1}·min^{-1}; HR: 193 ± 8 b·min^{-1}; $\dot{V}_E$: 60.7 ± 14.2 L·min^{-1}; RER: 1.03 ± 0.12; RPE: 9.4 ± 1.1; Marbles: 44.4 ± 9.6.

5.4.1 The characteristics of the perceptual response to increasing cycling work rate:

When utilising individual data across the full range of relative WR (e.g. 10 – 120 W), no significant differences ($P > 0.025$) were noted between the mean linear or curvilinear relationships ($R^2 = 0.93$ & $R^2 = 0.94$, respectively), for the E-P scale. Fisher *Zr* correlations were however significantly higher ($t_{(14)} = -4.15$, $P < 0.01$) for the curvilinear relationship than for the linear relationship between marbles and WR (R^2 = 0.94 & $R^2 = 0.80$, respectively).

5.4.2 Physiological and perceptual responses to increasing cycling work rate:

Fifteen children completed the first seven stages (70 W) of the exercise test, 14 completed stage 8, 10 completed stage 9, 6 completed stage 10, 3 completed stage 11 and 2 completed stage 12 (120 W). Repeated-measures ANOVA, employed on data from the initial seven stages, revealed highly significant increases in $\dot{V}O_2$ ($F_{(6, 84)}$ =

272.19, $P < 0.001$), HR ($F_{(2.6, 36.5)} = 469.9$, $P < 0.001$), $\dot{V}_E$ ($F_{(2.1, 29.9)} = 110.3$, $P < 0.001$), E-P scale RPE ($F_{(1.8, 25.7)} = 50.1$, $P < 0.001$), and marble task RPE ($F_{(1.6, 21.9)} = 29.6$, $P < 0.001$) with successive increases in exercise intensity. In consideration of children reaching maximal volitional exhaustion at different stages of the exercise test, a series of paired *t* tests were utilised on the remaining data from stages 8 to 12 to allow exploration of the widest range of physiological and perceptual data collected. For all variables, further significant increases ($P < 0.05$) were observed across stages 7 to 8 ($t_{(13)} = -5.01$, $t_{(13)} = -16.61$, $t_{(13)} = -4.28$, $t_{(13)} = -4.58$, & $t_{(13)} = -3.98$ for $\dot{V}O_2$, HR, $\dot{V}_E$, E-P scale RPE & marbles, respectively) and stages 8 to 9 ($t_{(9)} = -7.75$, $t_{(9)} = -9.54$, $t_{(9)} = -2.97$, $t_{(9)} = -4.39$, & $t_{(9)} = -3.22$ for $\dot{V}O_2$, HR, $\dot{V}_E$, E-P scale RPE & marbles, respectively). In addition, significant increases ($P < 0.05$) in HR were observed across stages 9 to 10 and 10 to 11 ($t_{(5)} = -3.49$, & $t_{(2)} = -14.00$, respectively). At the higher exercise intensities, and between stages 3 and 4 for the RPE measured by the E-P scale, no significant increases ($P > 0.05$) were observed with increasing power output (see Figures 5.4, 5.5, 5.6, 5.7 & 5.8).

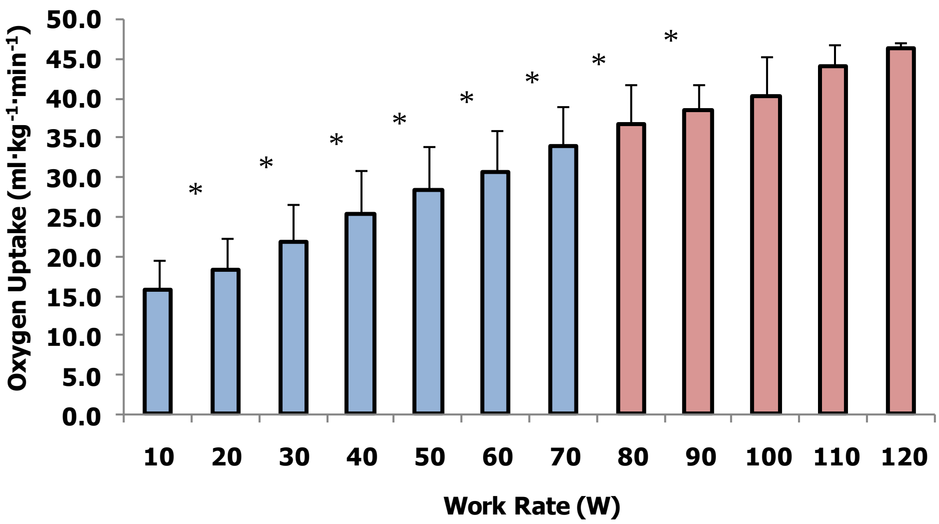

Figure 5.4. Oxygen uptake ($\dot{V}O_2$; ml·kg^{-1}·min^{-1}) at each work rate (W) throughout the graded-exercise test to exhaustion. Values are mean ± SD.

* Significant increase ($P < 0.05$) in oxygen uptake with increasing work rate.

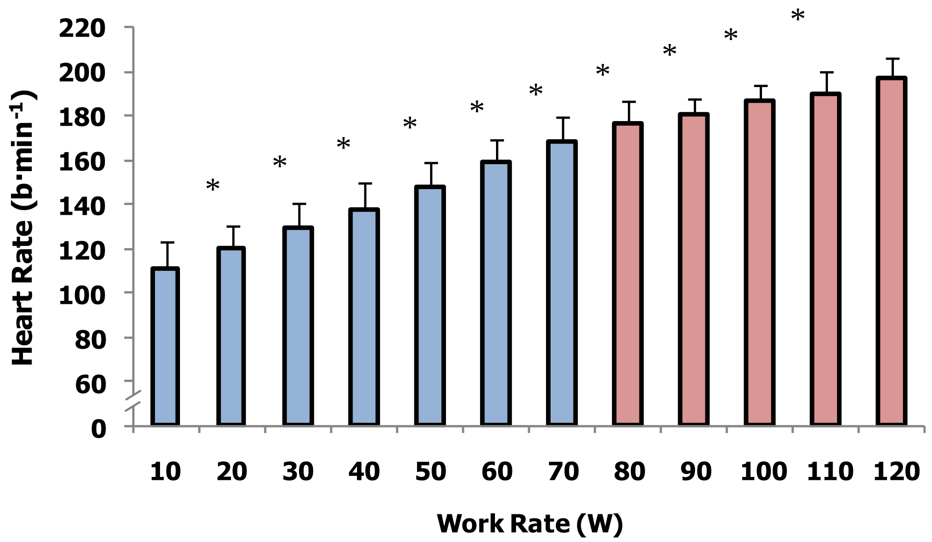

Figure 5.5. Heart rate (HR; b·min^{-1}) at each work rate (W) throughout the graded-exercise test to exhaustion. Values are mean ± SD.

* Significant increase (P < 0.05) in heart rate with increasing work rate.

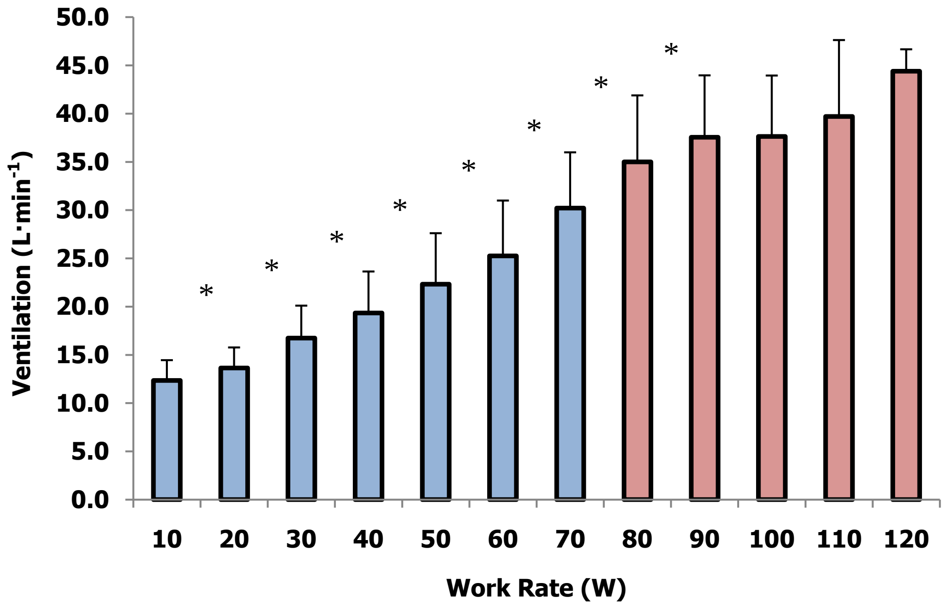

Figure 5.6. Ventilation ($\dot{V}_E$; L·min^{-1}) at each work rate (W) throughout the graded-exercise test to exhaustion. Values are mean ± SD.

* Significant increase (P < 0.05) in ventilation with increasing work rate.

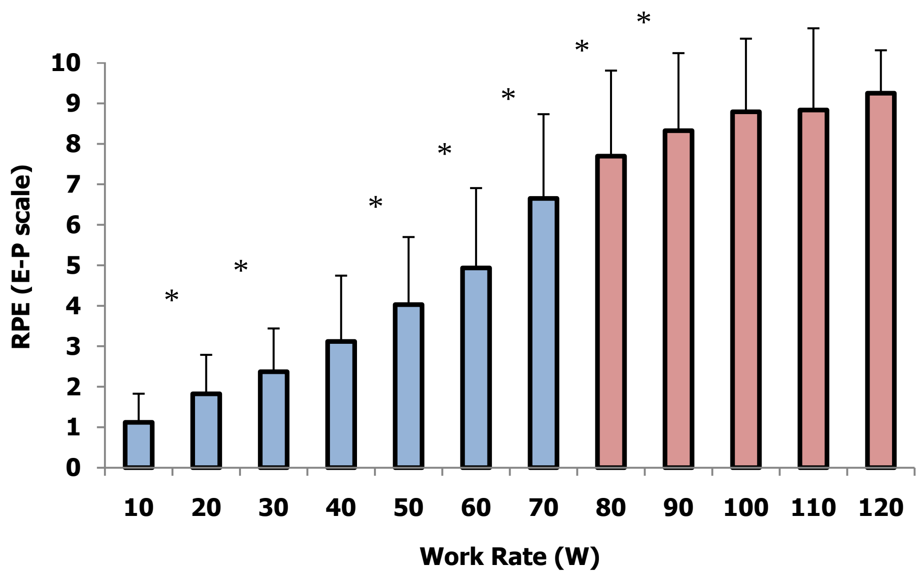

Figure 5.7. Ratings of perceived exertion (E-P scale) reported at each work rate (W) throughout the graded-exercise test to exhaustion. Values are mean ± SD.

* Significant increase ($P < 0.05$) in ratings of perceived exertion with increasing work rate.

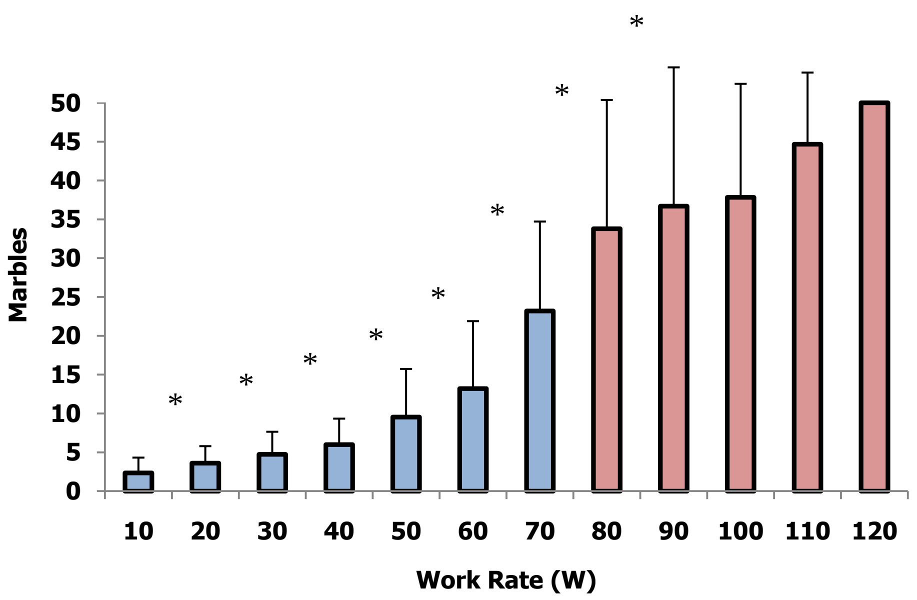

Figure 5.8. Number of marbles reported at each work rate (W) throughout the graded-exercise test to exhaustion. Values are mean ± SD.

* Significant increase ($P < 0.05$) in number of marbles with increasing work rate.

5.4.3 Further analysis on the physiological responses to increasing cycling work rate:

The $\dot{V}O_2$ (R^2 = 0.97), HR (R^2 = 0.99), and $\dot{V}_E$ (R^2 = 0.96) responses of all participants in this study demonstrated corresponding increases with WR throughout the exhaustive exercise test, as evidenced in the high average coefficients of determination.

5.4.4 Physiological responses in relation to RPE during cycle ergometry:

Table 5.1 demonstrates the coefficients of determination for the relationships (linear; curvilinear) between RPE (E-P scale; marbles) and several physiological variables ($\dot{V}O_2$; HR; $\dot{V}_E$), which may be considered potential mediators of the perceptual response. Interestingly, although no differences were noted between linear- and curvilinear relationships for the E-P scale, a curvilinear trend was consistently higher ($P < 0.008$) between the marbles and each of the physiological variables investigated ($\dot{V}O_2$: $t_{(14)}$ = -7.47; HR: $t_{(14)}$ = -5.31; $\dot{V}_E$: $t_{(14)}$ = -3.01).

Table 5.1. Coefficients of determination for the relationships (linear; curvilinear) between RPE (E-P scale; marbles) and physiological variables ($\dot{V}O_2$; HR; $\dot{V}_E$) throughout the graded-exercise test.

	RPE: $\dot{V}O_2$	RPE:HR	RPE: $\dot{V}_E$	Marbles: $\dot{V}O_2$	Marbles:HR	Marbles: $\dot{V}_E$
Linear	R^2 = 0.88	R^2 = 0.92	R^2 = 0.90	R^2 = 0.77	R^2 = 0.79	R^2 = 0.86
Curvilinear	R^2 = 0.92	R^2 = 0.88	R^2 = 0.88	R^2 = 0.92*	R^2 = 0.93*	R^2 = 0.92*

* Significantly ($P < 0.008$) stronger than the corresponding relationship (linear; curvilinear), for the same variable.

5.4.5 Physiological mediators of the perceptual response via hierarchical regression:

The results of the hierarchical regression analyses, utilised to assess the additive contribution of $\dot{V}O_2$, HR or $\dot{V}_E$ in accounting for any variance in the RPE responses, are shown in Table 5.2.

It is notable that $\dot{V}_E$ explained the most significant proportion of the overall variance in RPE response (63.1 %) when analysed as the main IV (59.9 % & 59.7 %; $P < 0.001$, using the E-P scale & marble task, respectively). A slightly lesser amount of variance was explained by either HR (57.8 %) or $\dot{V}O_2$ (54.4 %) for the E-P scale, when they were each inserted into the regression model as the main IV. However, when assessing the RPE from the marble task, the amount of variance explained by HR and $\dot{V}O_2$ (main IV) decreased further to 44.9 % and 50.7 %, respectively.

5.4.6 RPE exponents during cycle ergometry:

The average exponent for the E-P scale and WR was 1.03 (range: 0.53 – 1.69). For the marble task, the average exponent was 1.3 (range: 0.58 – 1.98) in conjunction with WR.

5.4.7 Supplementary analyses of consistency:

With regards to the variation in pedal cadence for all children in this study, subsequent analysis of the collated pedal revolution data revealed that children cycled at an average of 72.4 ± 4 rev·min^{-1} throughout all exercise stages, and 71.7 ± 4 rev·min^{-1} during the final 15-s of each exercise stage. This equated to a coefficient of variation range of 2.4 – 6.9 % across exercise tests, for all participants in this study.

No significant differences were observed for the strength of the relationships between RPE and WR ($t_{(6)} = 0.67$, $P > 0.05$) for children who rated their perception of exertion using the E-P scale first (R^2 = 0.94) or for those who used the marbles first (R^2 = 0.93).

Table 5.2. Total- and partial variance in the RPE response (E-P scale & marble task) that is explained by individual physiological variables (oxygen uptake, $\dot{V}O_2$; heart rate, HR; ventilation, $\dot{V}_E$) using a hierarchical regression model.

			***R^2* Change**		
DV	**IV Order of entry**	**Total Variance (%)**	**$\dot{V}O_2$ Variance (%)**	**HR Variance (%)**	**$\dot{V}_E$ Variance (%)**
E-P scale	$\dot{V}O_2$ / HR / $\dot{V}_E$	63.1	54.4*	5.2*	3.4*
	$\dot{V}O_2$ / $\dot{V}_E$ / HR	63.1	54.4*	2.7*	5.9*
	HR / $\dot{V}O_2$ / $\dot{V}_E$	63.1	1.8*	57.8*	3.4*
	HR / $\dot{V}_E$ / $\dot{V}O_2$	63.1	0	57.8*	5.2*
	$\dot{V}_E$ / $\dot{V}O_2$ / HR	63.1	0.5	2.7*	59.9*
	$\dot{V}_E$ / HR / $\dot{V}O_2$	63.1	0	3.1*	59.9*
Marbles	$\dot{V}O_2$ / HR / $\dot{V}_E$	59.8	50.7*	0.6	8.4*
	$\dot{V}O_2$ / $\dot{V}_E$ / HR	59.8	50.7*	0	9.0*
	HR / $\dot{V}O_2$ / $\dot{V}_E$	59.8	6.5*	44.9*	8.4*
	HR / $\dot{V}_E$ / $\dot{V}O_2$	59.8	0	44.9*	14.9*
	$\dot{V}_E$ / $\dot{V}O_2$ / HR	59.8	0	0	59.7*
	$\dot{V}_E$ / HR / $\dot{V}O_2$	59.8	0	0	59.7*

* Significant additive contribution to the RPE response ($P < 0.05$)

5.5. Discussion:

This study assessed the validity of the E-P scale during an incremental GXT to volitional exhaustion on a cycle ergometer with healthy 7 – 8 year-old children. The successive increases in perceived exertion with increments in exercise intensity indicate that children readily understood the nature and purpose of the E-P scale. Furthermore, without a prior active familiarisation bout of exercise, the children were able to use the scale to accurately estimate their perception of exertion throughout the exercise test. Equally strong linear and curvilinear coefficients of determination (R^2) were observed between the E-P scale and work rate (R^2 = 0.93 & R^2 = 0.94, respectively). The young children in this study were also able to comprehend and apply the novel perceptual marble task effectively, providing an accurate indication of their perception of effort for the duration of the test. The strong curvilinear relationship demonstrated between the marble task and work rate (R^2 = 0.94) provides further support for the use of a curvilinear ratings of perceived exertion scale with normal, healthy young children.

5.5.1. Changes in the RPE with increasing exercise intensity:

As the children understood from the outset that the stages in the exercise test would become progressively harder, it is plausible to assume that the rise in their perceptual responses may have been the result of anticipatory bias. However, the equally high linear and curvilinear R^2 values, for the RPE reported through the E-P scale and increasing exercise intensity (WR, $\dot{V}O_2$, $\dot{V}_E$, HR), demonstrate that all the children understood and could utilise the E-P scale to provide valid ratings of perceived exertion. Furthermore, our data demonstrate the robustness of the E-P scale to detect both linear and curvilinear growth functions of the children's perceptual responses during incremental cycling exercise.

5.5.2. Physiological mediators of the perceptual response:

The specific factors that affect RPE determination in children remain unknown (Mahon & Ray, 1995). Ventilation has been suggested as a potential cue for perceptual responses given that it is an accepted physiological mediator for respiratory-metabolic signals of exertion during endurance exercise (Eston & Parfitt, 2007). The preliminary results of the simple regression analyses (see 5.4.4) in this study would suggest that ventilation may be a strong mediator of perceptual responses, as indicated by the high R^2 values. However, equivalently strong relationships noted for $\dot{V}O_2$ and HR with RPE suggests that they too may be influential factors in determining an individual's perception of exertion. Subsequent investigation using hierarchical regression analyses (Table 5.2) suggest that ventilation alone explains the most variance in the RPE response during cycle ergometry exercise. However, it should be noted that $\dot{V}O_2$ and HR also explained a significant proportion of the overall variance in RPE responses, with young children.

5.5.3. The nature of the perceptual response to cycling exercise in young children:

The statistically higher curvilinear R^2 value (R^2 = 0.94) observed for the relationship between perceived exertion assessed from the marble task and work rate suggests that the perception of exertion for a child aged 7 – 8 years may rise in a curvilinear fashion in response to equal and gradual increments in work rate, which in this study equated to between 1-2 child-specific metabolic equivalents for this age range (5.92 $ml \cdot kg^{-1} \cdot min^{-1}$; Harrell et al., 2005). For the participants in this study, exponents in the range 0.58 – 1.98 were generated for the RPE response when this was calculated from the natural logarithmic values of the individual relationships between the RPE from the marble task and work rate. This equated to an average exponent of 1.3 ± 0.8, which is in accordance with previous research that has demonstrated exponents of approximately 1.6 in studies on short-term perceived exertion during cycle ergometry (Borg, 1998; Borg & Dahlström, 1959; Borg, et al., 1970). Indeed, it is important to recognise that prior to the formation of the Borg 6-20 RPE scale, upon which many of the subsequent (linear) child-specific RPE scales were based, psychophysical studies investigating subjective force and perceived exertion during cycle ergometry demonstrated nonlinear functions between the ratio data of perceived intensity and physical work load (Borg, 1970; Borg & Dahlström, 1960).

The slope of the E-P scale was originally based on a simple power function ($R = c \cdot S^n$) as described by Borg (1998). As such, the slope of the hill (from number 2 – 10 on the horizontal axis) depicted pictorially in Figure 2.8, was designed with an exponent of approximately 3. This is in keeping with previous research that has yielded an exponent of 3 during treadmill walking and running (Borg, 1973, 1998). However, the overall exponent for the E-P scale when calculated across the full numerical range (0 – 10), is 1.04. This is a consequence of the pictorial design, in that the exponent is reduced when the calculation takes into account the significant portion of the base of the hill (0 – 2.5) which is parallel to the horizontal axis. Individual analyses, comparable to those performed with the marble task data, between the RPE responses from the E-P scale and work rate revealed exponents in the range 0.53 – 1.69. This constitutes an average exponent of 1.03, which is appreciably similar to the exponent generated in the design of E-P scale.

5.5.4. Characteristics of the E-P scale:

As in the familiar Borg Category-Ratio 10 (CR10) scale (Borg, 1998), the E-P scale encompasses both category and ratio properties. However, unlike the CR10, the E-P scale does not permit free magnitude estimation. Rather, it has a fixed end-point, or an upper reference to which participants can anchor their perceptions. The character utilised on the E-P scale, depicted in rising stages of exertion on a progressively increasing gradient complements the assumption that from prior learning and experience, a child will readily conceive that *the steeper the hill, the harder it is to ascend* (Lamb et al., 2008). The distinct characteristic of the numerical range utilised on the E-P scale similarly reflects the rise in the RPE during the higher intensities of exercise, corresponding with the pictorial-descriptors. Furthermore, in the initial development of the E-P scale, the locations of the stylised figures were chosen by children according to where they perceived they should be (Eston & Parfitt, 2007). On this basis, the E-P scale holds inherently obvious face validity.

It is unknown, however, if the ambulatory figure depicted in the E-P scale was a primary focus of the child's attention. It is also unknown whether a 'cycling' figure may have led to even greater perceptual acuity of the exertion experienced by the child during the 'cycling' task in this study. Despite the modality of exercise depicted in the scale not being congruent with the exercise task, it has been observed by Parfitt et al. (2007) that a mode-specific stepping scale (BABE) and a mode-specific cycling scale (CALER) may be used interchangeably for intra- and intermodal regulation of effort production in young children aged 9 – 10 years. This infers that a mode-specific RPE scale may not be necessary for a child to accurately gauge the sensation of exertion. Further to this, the resultant exponents generated by the marble task in this study reflect rather more closely those observed during cycle ergometry exercise (exponent of approximately 1.6) than those observed during either walking or running exercise (exponent of approximately 3), as depicted on the E-P scale. Prior research has also indicated that the gender of the pictorial descriptors does not systematically influence perceptual responses (Roemmich et al., 2006). However, the relative influence of the visual information (pictorial-, numerical-, or verbal descriptors) has yet to be established when determining a suitable perceptual rating using the E-P scale.

5.5.5. Curvilinear RPE responses in past literature:

Although this is the first study to utilise a curvilinear RPE scale for the purpose of estimating exercise effort in children, curvilinear relationships between perceived exertion and variables such as HR and power output have been previously documented in the paediatric literature. In a study by Lamb (1995) which utilised the CERT in a passive estimation mode, the HR data of 36 boys and girls aged 9 – 10 years manifested considerable disparity, particularly at higher exercise intensities, when compared against the linear conceptual model on which the CERT was originally based (Williams et al., 1994). Moreover, the author noted a similar, non-linear trend between the RPE data from the CERT and increasing power output. When these data were fit with a curvilinear model, notable improvements in correlation were observed (Lamb, 1995). Barkley & Roemmich (2008) have further corroborated these findings. In their study, boys and girls (aged 9.5 ± 0.7 y & 9.4 ± 0.8 y, respectively) performed a continuous, incremental exercise test to $\dot{V}O_2$peak on a cycle ergometer, and estimated RPE every minute using both the CALER and OMNI perceived exertion scales. They revealed that children reported terminal RPE values that were statistically lower ($P \leq 0.001$; 75 ± 20 % and 74 ± 19 % of theoretical maximal (RPE 10) for CALER & OMNI, respectively) than the proportion of predicted maximal heart rate (94.5 ± 3 %) achieved during the final stage of the exercise test (Barkley & Roemmich, 2008). Moreover, a study by Roemmich et al. (2006) on boys and girls (aged 11.2 ± 1.6 y & 11.1 ± 1.4 y, respectively) has indicated similar findings, reporting that at 82 % of HR maximum and 70 %$\dot{V}O_2$peak during a progressive, submaximal treadmill protocol, children corresponded with only 52 % of the maximum value on the RPE scale. This infers that perceived exertion tracks according to a positively accelerated function, as has been documented previously with adults (Borg, 1998; Borg & Dahlström, 1959).

5.5.6. Terminal RPE responses of young children:

Despite small rises in $\dot{V}O_2$, HR, $\dot{V}_E$, RPE from the E-P scale & marbles during the latter stages of the exercise test (approximately 90 – 120 W), no statistical differences were noted with each increase in exercise intensity using paired *t* tests. This is likely attributed to the limited number of participants who continued to exercise to these higher exercise intensities, and the resultant decrease in statistical power of the analyses. However, the high coefficients of determination calculated for individual physiological responses with relative maximal work rate provide a further assurance of a continued increase in these variables to maximum, for each participant. Thus, the lack of statistical difference may merely reflect similarities in the maximal physiological and perceptual responses obtained from each of these participants at the point of exhaustion. From the maximal physiological data (see 5.4), we are satisfied that all participants reached $\dot{V}O_2$peak at termination of the exercise test. Furthermore, the standardised instructions and anchoring of the perceptual responses for both the E-P scale and the marble task were deemed sufficient to allow confidence in the maximal RPE responses of each child in this study.

In this regard, it is notable that the average terminal RPE (mean ± SD) reported at $\dot{V}O_2$peak for all participants was RPE 9.4 (± 1.1), which was slightly, but significantly lower than the theoretical maximal RPE (10) according to the E-P scale ($t_{(14)}$ = -2.17, P < 0.05). A similar finding was observed with the marble task, wherein the average terminal quantity of marbles (mean ± SD) selected by all 15 participants in this study (44.4 ± 9.6) was significantly lower than the theoretical maximal quantity of marbles (50; $t_{(14)}$ = -2.25, P < 0.05). These findings are in accordance with previous research conducted with adults, which have noted that the theoretical maximal RPE on the Borg 6-20 RPE scale is infrequently reported at volitional exhaustion (Eston et al., 2007; Faulkner et al., 2007; Kay et al., 2001; St Clair Gibson et al., 1999). It is noteworthy that these findings are also in accordance with those of Barkley and Roemmich (2008), albeit to a lesser extent; in that the terminal RPE was lower than theoretical maximal RPE value at a similar maximal physiological output. However, as the proportional difference between the maximal RPE and maximal exercise intensity is much smaller in the current study (96 % of total RPE scale reported) compared to the study by Barkley and Roemmich (75 % & 74 % of total RPE scale reported at 94.5 % of predicted HRmax) we suggest that the curvilinear design of the E-P scale may present a more appropriate tool to reflect the cognitive developmental characteristics of a child's perceived exertion response.

5.5.7. Influence of age- and cognitive development:

This study utilised participants of a young age-range (7 – 8 years). It is clear that the children in this study were in the 'Concrete Operations Period' of their cognitive development, according to Piaget (1999), as they understood the three-dimensional aspects involved in the marble task (number, volume and weight of the marbles) and simultaneously were able to interpret the two-dimensional curvilinear pictorial scale. This demonstrates the ability for 'conservation of quantity' and 'decentering', which are fundamental to this phase of the child's development (Child, 1977).

5.5.8. Influence of protocol:

This study utilised the RPE in a passive estimation paradigm which is similar to many previous investigations on perceived exertion in children (Barkley & Roemmich, 2008; Groslambert & Mahon, 2006; Mahon & Ray, 1995; Marinov et al., 2008; Robertson et al., 2000; Roemmich et al., 2006; Utter et al., 2002b). However, the protocol employed in this study was discontinuous and incremental in style, which is unlike many previous studies in this area. Lamb et al. (1997) assessed the influence of protocol on the relationship between perceived exertion (CERT) in children (9 – 10 years) using a production paradigm. They reported significantly higher correlations ($P < 0.05$) between perceived exertion (CERT) and heart rate using a discontinuous protocol when compared to a continuous protocol (r = 0.66 & r = 0.46). Although somewhat limited, Eston and Parfitt (2007) have also provided evidence to suggest that an intermittent protocol may be preferable over a continuous protocol during a passive estimation procedure, for an 8 year-old child. As acceptable physiological and perceptual criteria for reaching $\dot{V}O_2$peak were elicited by each participant in this study, we are satisfied that a discontinuous protocol was appropriate for this study.

5.5.9. Other methodological implications:

In this study, the children were also able to cope with the process of estimating via the two distinct procedures whilst simultaneously maintaining a fixed pedal cadence. The possibility that 'dual loading' would influence pedal cadence was discounted on the basis of a low coefficient of variation of their pedal revolutions data throughout each test (2.4 – 6.9 %). Similarly, as large intra-individual variation in pedal cadence throughout an exercise test may impede accurate determination of perceptual growth functions in relation to work rate (IV), the low coefficient of variation in pedal cadence reported in this study permits assurance that the overall interpretation of the perceived exertion response in relation to work rate is acceptable.

It is important to note that the E-P scale was visible to all participants throughout the duration of the test. Despite randomising the order in which each participant was presented with the methods of rating their perceived exertion (i.e. E-P scale prior to marbles; marbles prior to E-P scale), it is potentially feasible that the visibility of the E-P scale may have influenced the subsequent selection of marbles. However, further analysis confirmed that there were no statistical differences in the relationship between the RPE and work rate between the children who rated using the E-P scale first (R^2 = 0.94) or those who used the marbles first (R^2 = 0.93). Similarly, it is feasible to assume that intra-individual differences in RPE response may result from the alternate use of the point and slide procedures when using the E-P scale. Although this was not formally assessed, it is noteworthy that all the children in the present study chose either to point to the scale *or* slide the marker when rating their perceived exertion, which they repeated through choice for the duration of their test.

Despite the sample size (15 children) being large enough to exact statistical differences from the analyses, a larger sample would aid in generalising these findings to the wider population.

5.6. Conclusion:

The results of this study provide evidence in support of the validity of the E-P scale to provide estimates of perceived exertion in healthy children, aged 7 – 8 years. The novel psycho-physical marble dropping task employed in this study offered a valuable and interesting insight into a child’s method of deriving valid exertional ratings. These findings challenge conventional understanding and question available methods of assessing perceived exertion in children. The unique observations in this study are encouraging and indicate that a child’s perception of exertion may rise curvilinearly with equal increments in work rate.

The findings of this study concur with the postulation that a curvilinear gradient may be more ecologically valid for use with children. Particularly as ventilation may be a predominant cue of the perceptual response in young children, and ventilation is known to rise in a curvilinear fashion with increasing work. The E-P scale has such a gradient, and therefore has inherent face validity as such visual representation may facilitate a child’s understanding and thus his or her ability to use the scale. A single exercise test was used for the purpose of estimation in this study, with no assigned period of habituation. Future studies are recommended to investigate the validity and reliability of the E-P scale across differing exercise modes, and to further consider the influence of physiological variables on the perceptual responses of children of this age.

Chapter 6

Study 4

Assessment of perceived exertion during treadmill exercise using the Eston-Parfitt Scale and marble dropping task, in children aged 7 – 8 years.

This study has contributed to the following publication:

Publication:

Lambrick, D.M., Rowlands, A.V., & Eston, R.G. The perceptual response to treadmill exercise using the Eston-Parfitt Scale and marble dropping task, in children aged 7 – 8 years. *Pediatric Exercise Science*, In press.

6.1 Abstract:

This study assessed the nature of the perceived exertion response to treadmill running in 14 healthy 7 – 8 year-old children, using the Eston-Parfitt (E-P) Ratings of Perceived Exertion (RPE) scale and a marble dropping task. For the E-P scale and the marble dropping task, the relationships between the RPE and work rate were best described as linear (R^2 = 0.96) and curvilinear (R^2 = 0.94), respectively. This study further suggests that individual respiratory-metabolic cues (oxygen uptake: $\dot{V}O_2$, heart rate: HR, ventilation: $\dot{V}_E$) may significantly influence the overall RPE to varying degrees in young children. The E-P scale provides an intuitively meaningful and valid means of quantifying the overall perception of exertion in young, healthy children during treadmill running. The marble dropping task is a useful secondary measure of perceived exertion, which provides further insight into the nature of the perceived exertion response to exercise in young children.

6.2 Introduction:

A number of ratings of perceived exertion (RPE) scales exist to assess perceived exertion during various modes of exercise in children (for review, see chapter 2 & study 3; Coquart, Lensel, & Garcin, 2009c; Eston & Parfitt, 2007; Lamb et al., 2008). The combination of numerical, verbal and pictorial descriptors which make up the scales are purported to be ‘developmentally-appropriate’ for the age and cognitive development level of children. With regards to most of the pictorial scales, the rationale to depict a figure at varying stages of exertion on either a horizontal line or a linear gradient is founded on a strong, positive and linear relationship between the RPE and oxygen uptake ($\dot{V}O_2$), heart rate (HR) and power output during exercise. However, there is some evidence to suggest that the RPE in young children may rise according to a positive function in relation to such variables as power output or heart rate (study 3; Barkley & Roemmich, 2008; Lamb, 1995; Roemmich et al., 2006).

6.2.1 Newly devised curvilinear RPE scale:

Recently, a curvilinear scale (Eston-Parfitt; E-P scale; Figure 2.8) has been devised to assess RPE in young children (study 3; Eston & Parfitt, 2007). In the design of the E-P scale, it was postulated that children would readily conceive that *the steeper the hill, the harder it is to ascend* (Lamb et al., 2008). Moreover, in consideration that ventilation ($\dot{V}_E$) may be a mediating factor in the respiratory-metabolic signals of exertion in children, such as in adults (chapter 2; Noble & Robertson, 1996), and $\dot{V}_E$ is known to rise in a positively accelerating function above work rates of ~ 60 % $\dot{V}O_2max$ (Orenstein, 1993; Rowland, 2005), it is plausible that concurrent increases in RPE may be observed at the higher exercise intensities. Yet, the preliminary findings of study 3 suggested that during cycle ergometry exercise, $\dot{V}_E$ may not be the predominant mediator of the perceptual response. Additionally, it was unclear from the findings of study 3 to what extent other physiological variables, such as HR or $\dot{V}O_2$, may mediate the perceptual response to increasing exercise in young children.

6.2.2 Validation of E-P scale:

Study 3 of this thesis confirmed the validity of the E-P scale for cycling in children aged 7 – 8 years using a discontinuous, incremental exercise test to volitional exhaustion. Ratings of perceived exertion were assessed at frequent intervals throughout the test utilising the E-P scale and a novel psycho-physical marble task. Both assessment methods indicated that the relationship between effort perception and exercise intensity in young children aged 7 – 8 years may often be curvilinear in nature.

6.2.3 Purpose and hypotheses:

The purpose of this study was to extend the findings of study 3 by examining the nature of the perceptual response to treadmill exercise in healthy children, aged 7 – 8 years, using the E-P scale and marble task. As the marble dropping task was shown to be useful in identifying both linear and curvilinear growth functions in the RPE in the aforementioned cycle ergometry study, we were interested in comparing the results from the same method during a graded treadmill exercise test, particularly as the E-P scale depicts a character who is walking and running up a progressively increasing gradient. It was also of interest to further establish whether one particular physiological cue ($\dot{V}O_2$, HR, $\dot{V}_E$) may mediate the perceptual response during treadmill exercise in young children, and to ascertain whether exercise mode may influence the nature of the perceptual response. We hypothesised that the relationships between the RPE, WR and physiological parameters ($\dot{V}O_2$, HR, $\dot{V}_E$) would be similar to those observed previously during cycle ergometry (study 3), and that linear and curvilinear growth functions in the RPE would be detected.

6.3 Method:

6.3.1 Participants:

Fourteen healthy children (eight boys; age: 7.9 ± 0.4 y; height: 1.31 ± 0.05 m; body mass: 27.2 ± 3.5 kg, and six girls; age: 8.0 ± 0.0 y; height: 1.30 ± 0.04 m; body mass: 27.9 ± 4.1 kg) volunteered for this study, following recruitment using information sheets (Appendices 2e & 2f). Parents / guardians provided written informed consent (Appendix 2e) and participants provided informed assent (Appendix 2f), respectively, prior to the commencement of the study. The health status of each child was assessed using a ‘Health Screening’ form, which was completed by the parents / guardians

(Appendix 9). The study was approved by the Ethics Committee of the School of Sport and Health Sciences at the University of Exeter.

6.3.2 Procedures:

Following measurements of height and body mass (SECA, Hamburg, Germany), children were habituated to the treadmill speeds (5 $km \cdot h^{-1}$ & 8 $km \cdot h^{-1}$; Woodway GmbH PPS 55Med-I, Weil am Rhein, Germany) to be used in the graded exercise test (GXT). Children elected to walk or jog at these speeds until completely comfortable with the equipment. For all participants, the habituation period did not exceed 5-min. Treadmill speed was then halted and standardised instructions were provided detailing how to use the E-P scale and marble task during the GXT. No active familiarisation with the E-P scale or marble task was given. The instructions used for both the E-P scale and the marble task were modified from those used in study 3 (see section 5.3.3). Participants were also guided through memory-recall anchoring techniques using maximal values of the E-P scale and marbles task (10 & 50, respectively) as upper reference points for perceptual responses.

For procedures concerning equipment calibration and the measurement of physiological data (HR, $\dot{V}O_2$, $\dot{V}_E$, RER), refer to section 5.3.2 (study 3). Criteria for terminating the exercise test included exhaustion, in association with a HR approximating 200 $b \cdot min^{-1}$; respiratory exchange ratio (RER) ≥ 1.00; an evident plateau or peak in $\dot{V}O_2$, or < 2.1 $ml \cdot kg^{-1} \cdot min^{-1}$ increase in $\dot{V}O_2$ in the final stage of exercise (Rowland, 1996).

6.3.3 Graded exercise test (GXT) to $\dot{V}O_2max$:

Participants performed a single, discontinuous GXT to volitional exhaustion. The protocol comprised a series of 1-min ‘active’ bouts that successively increased in speed and/or gradient, and were separated by a series of 1-min ‘recovery’ bouts, whereby the participant stood still to report their RPE. The initial speed and incline of treadmill was set at 5 $km \cdot h^{-1}$ and 0%, respectively (i.e. first ‘active’ bout). Thereafter, a speed of 8 $km \cdot h^{-1}$ was used for each ‘active’ bout, initially at 0% gradient (i.e. second ‘active’ bout), and increasing by 2% for each subsequent ‘active’ bout until exhaustion. Speed and gradient of the treadmill were manually manipulated to ensure that the interim stages between each active bout and recovery were as swift as possible (< 10-s).

Within the first few seconds of each recovery period, participants were requested to estimate their level of exertion (from the previous active bout) using the two ratings methods. Procedures for employing the E-P scale (Figure 6.1) and marble task were identical to those employed during study 3, with two exceptions. Firstly, children were required to point to a number or corresponding site on the slope of the E-P scale to provide a rating of perceived exertion – no ‘slide’ method was available in this study. Secondly, once participants had provided their RPE using each method, all components (E-P scale or marbles) were removed from sight.

The question “*how hard did the exercise feel to you?*” was asked prior to each method being implemented. The order of each method was randomised between participants but remained consistent during each test.

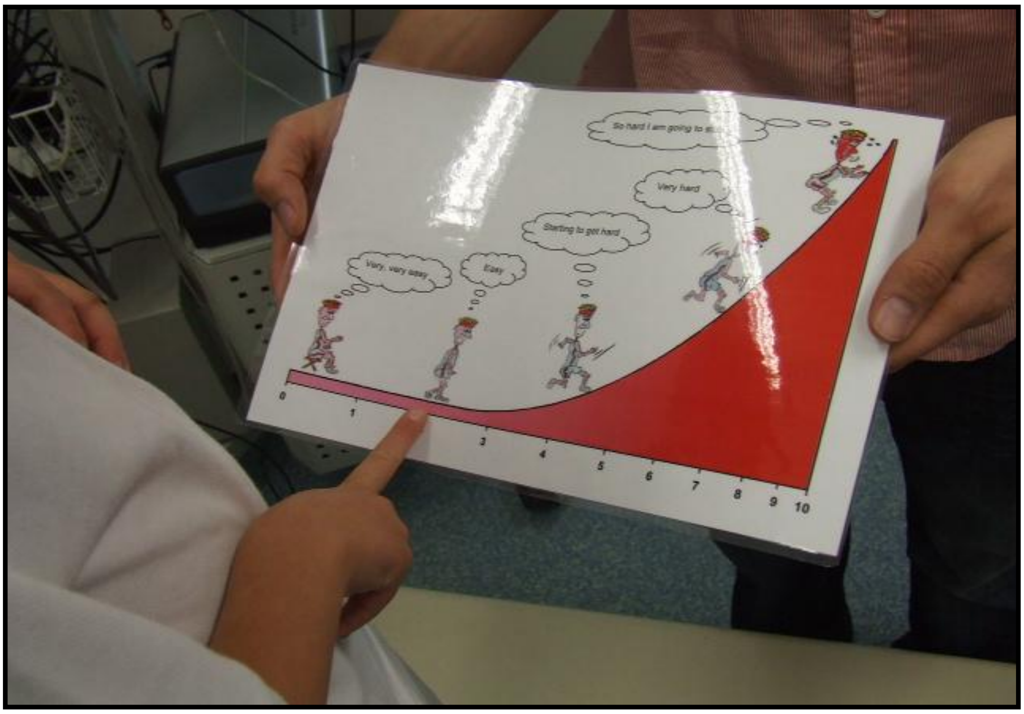

Figure 6.1. Participant rating his perception of exertion using the E-P scale, during the graded-exercise test to exhaustion on a motorised treadmill.

6.3.4 Data Analysis:

a) Characteristics of the RPE response:

Individual regression analyses were employed to assess the nature (curvilinear / linear) of the relationship between perceptual responses (E-P scale, marbles; dependent variable: DV) and increasing WR (exercise stages; independent variable: IV). Both linear and curvilinear models of 'best-fit' were applied to the data, and coefficients of determination (R^2) were calculated using Fisher's *Zr* transformation across relative maximal work rates for each participant. Paired *t* tests were subsequently employed to assess whether the relationship between RPE (E-P scale; marbles) and WR was significantly more linear or curvilinear in nature. Independent one-sample *t* tests were also conducted to assess whether the average terminal RPE responses of the participants in this study were significantly different to the theoretical maximal RPE values of each ratings method (E-P scale: 10; marble task: 50).

b) Physiological and perceptual response to increasing work:

Identical procedures to study 3 (see section 5.3.5b) were employed in this study to assess the physiological ($\dot{V}O_2$, HR, $\dot{V}_E$) and perceptual (RPE; E-P scale, marbles) responses to increasing work. Repeated-measures Analysis of Variance (ANOVA) were utilised across the first five stages of the exercise test for all participants. Between stages 5 - 12 of the treadmill protocol, a series of paired *t* tests (Bonferroni adjustment; $P < 0.007$) were employed on the physiological and perceptual data to account for the decreasing number of participants attaining the higher exercise intensities.

c) Physiological responses to increasing work rate:

Refer to section 5.3.5c for the methodology for assessing the physiological and perceptual response to increasing work rate.

d) Relationship between physiological variables and perceived exertion:

Refer to section 5.3.5d for the methodology for assessing the relationship between physiological variables and perceived exertion.

e) Hierarchical regression analysis to assess potential physiological mediators of the perceptual response:

Refer to section 5.3.5e for the methodology for conducting hierarchical regression analysis to assess potential mediators of the perceptual response, during treadmill exercise.

f) RPE exponents using the E-P scale and marble task:

The natural logarithmic values of the individual relationships between the RPE (E-P scale; marbles) and work rate were calculated for each participant in this study, and these were subsequently averaged to obtain a single exponent reflecting the nature of the relationship between these two variables.

g) Reliability of the perceptual responses:

An independent *t* test was utilised to assess the influence of the order in which each ratings method was employed (E-P scale or marble task first) on the RPE responses of the two randomly allocated groups of participants. Alpha was set at 0.05, and adjusted accordingly. All analyses were performed using the statistical package SPSS for Windows, version 15.0.

6.4 Results:

Maximal physiological and perceptual responses recorded at termination of the exercise test were (mean ± SD) $\dot{V}O_2$: 50.1 ± 8.3 ml·kg^{-1}·min^{-1}; HR: 198 ± 8.9 b·min^{-1}; $\dot{V}_E$: 55.1 ± 11.0 L·min^{-1}; RER: 1.12 ± 0.05; RPE: 9.7 ± 0.6; Marbles: 49.0 ± 2.9.

6.4.1 The nature of the perceptual response to increasing work rate:

Corresponding increases in RPE with WR were demonstrated for the E-P scale, with a paired *t* test across the complete range of exercise intensity revealing that the relationship between the RPE and WR was significantly linear (R^2 = 0.96 & R^2 = 0.89, linear and curvilinear, respectively; $t_{(13)}$ = 4.304, P < 0.01). For the marble task, the relationship between marbles and WR was significantly ($t_{(13)}$ = -2.319, P < 0.05) more curvilinear than linear (R^2 = 0.94 & R^2 = 0.88, respectively).

Independent *t* tests confirmed that there were no significant differences (P > 0.05) between terminal RPE responses and theoretical maximal RPE for both ratings methods (9.7 ± 0.6 cf. RPE 10, & 49.0 ± 2.9 cf. 50 marbles, for E-P scale and marble task, respectively).

6.4.2 Physiological and perceptual responses to increasing work rate:

ANOVA demonstrated significant increases in $\dot{V}O_2$ ($F_{(4, 52)} = 59.7$, $P < 0.001$), HR ($F_{(4, 52)} = 13.2$, $P < 0.01$), $\dot{V}_E$ ($F_{(4, 52)} = 69.2$, $P < 0.001$), RPE (E-P scale; $F_{(4, 52)} = 88.1$, $P < 0.001$) and marbles ($F_{(4, 52)} = 13.9$, $P < 0.01$) with increasing exercise intensity over the first 5 stages of the GXT. The $\dot{V}O_2$ also increased at stage 8 of the GXT ($t_{(12)} = -5.469$, $P < 0.007$). Increases ($P < 0.007$) in HR were observed at stages 6, 7 and 9 of the GXT ($t_{(12)} = -9.374$, $t_{(12)} = -3.736$, & $t_{(6)} = -4.044$, respectively) and in $\dot{V}_E$, at stages 9 and 10 ($t_{(9)} = -7.199$ & $t_{(6)} = -4.644$, respectively). The RPE (E-P scale) significantly increased ($P < 0.007$) across stages 6, 7, 8 and 9 of the GXT ($t_{(12)} = -4.284$, $t_{(12)} = -3.726$, $t_{(12)} = -4.549$ & $t_{(9)} = -3.643$, respectively), and the number of marbles selected increased ($P < 0.007$) across stages 6, 7 and 8 ($t_{(12)} = -4.163$, $t_{(12)} = -3.693$ & $t_{(12)} = -4.424$, respectively; see Figures 6.2, 6.3, 6.4, 6.5 & 6.6).

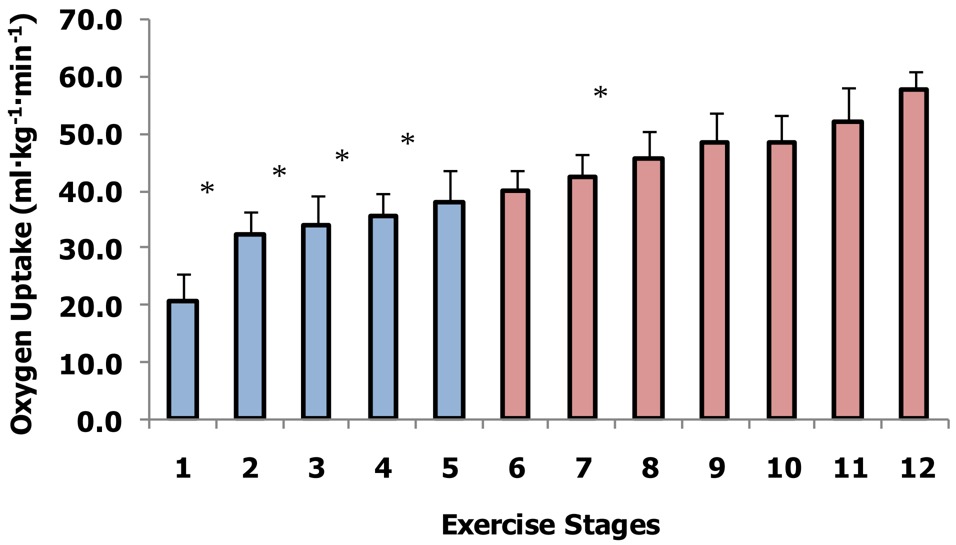

Figure 6.2. Oxygen uptake ($\dot{V}O_2$; ml·kg^{-1}·min^{-1}) at each exercise stage throughout the treadmill graded-exercise test to exhaustion. Values are mean ± SD.

* Significant increase ($P < 0.007$) in oxygen uptake with increasing work rate.

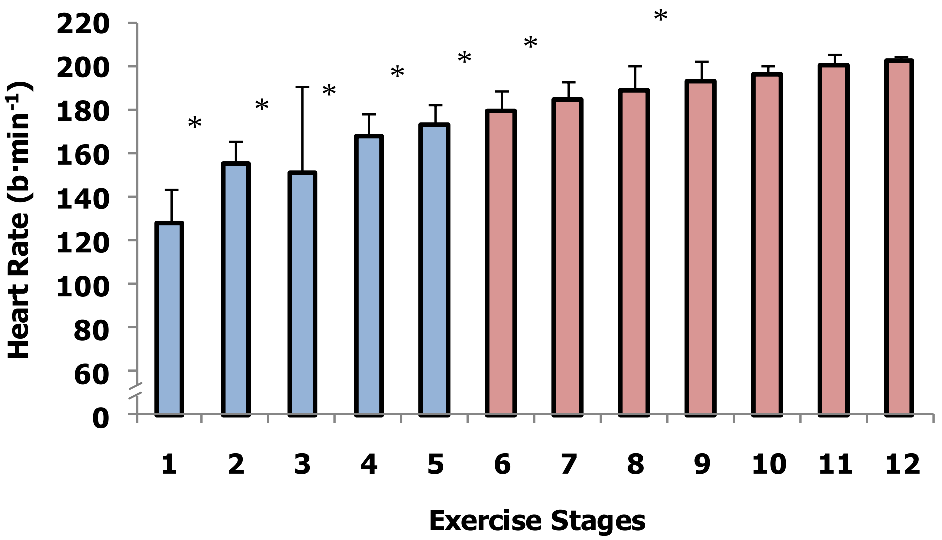

Figure 6.3. Heart rate (HR; b·min^{-1}) at each exercise stage throughout the treadmill graded-exercise test to exhaustion. Values are mean ± SD.

* Significant increase ($P < 0.007$) in heart rate with increasing work rate.

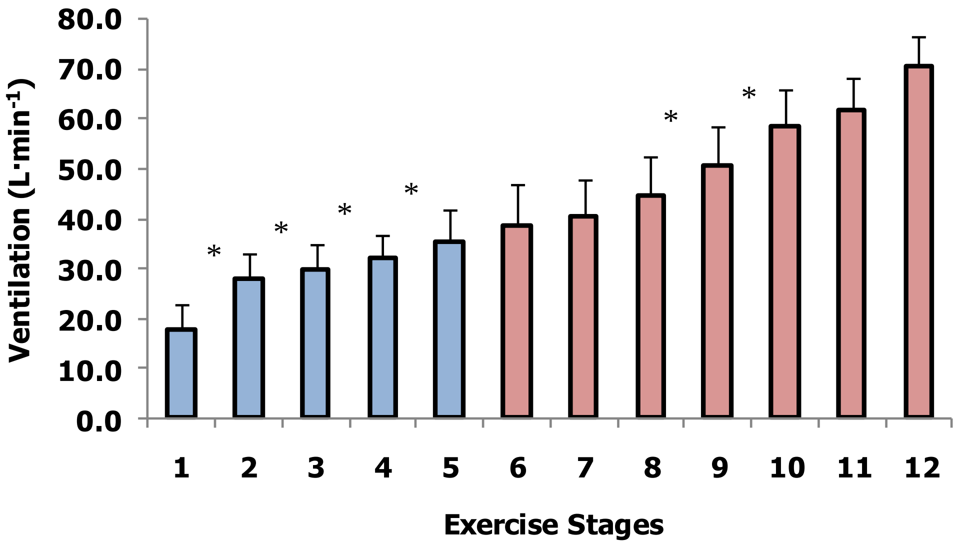

Figure 6.4. Ventilation ($\dot{V}_E$; L·min^{-1}) at each exercise stage throughout the treadmill graded-exercise test to exhaustion. Values are mean ± SD.

* Significant increase ($P < 0.007$) in ventilation with increasing work rate.

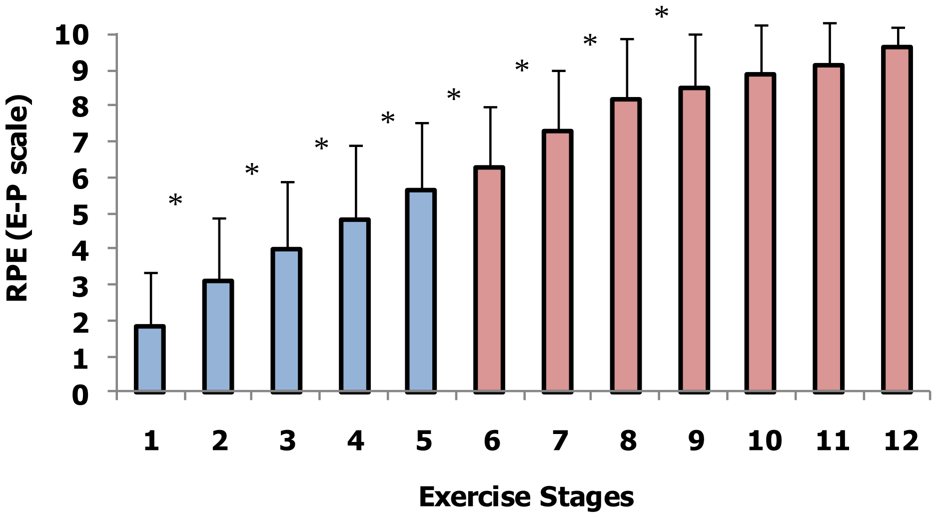

Figure 6.5. Ratings of perceived exertion (E-P scale) reported at each exercise stage throughout the treadmill graded-exercise test to exhaustion. Values are mean ± SD.

* Significant increase ($P < 0.007$) in ratings of perceived exertion with increasing work rate.

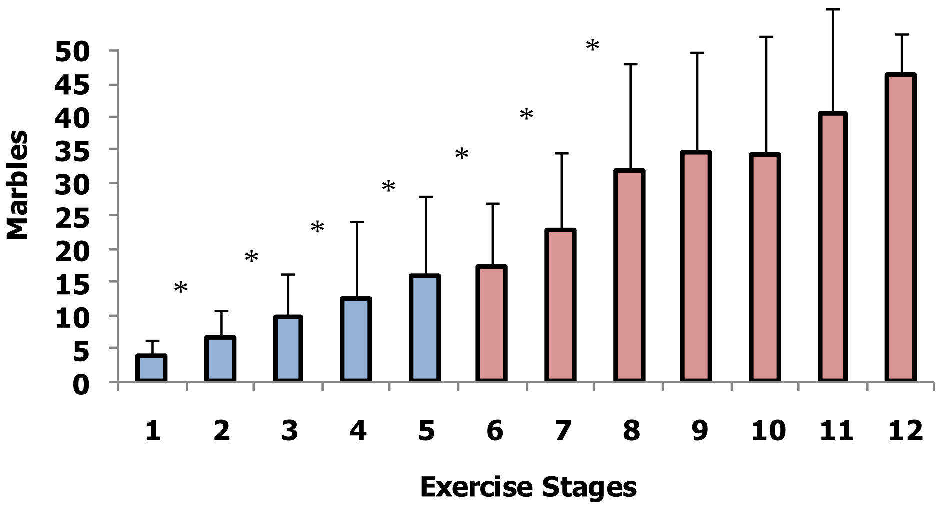

Figure 6.6. Number of marbles reported at each exercise stage throughout the treadmill graded-exercise test to exhaustion. Values are mean ± SD.

* Significant increase ($P < 0.007$) in number of marbles with increasing work rate.

6.4.3 Further analysis of physiological responses to increasing work rate:

For all participants, $\dot{V}O_2$ (R^2 = 0.85), HR (R^2 = 0.90), and $\dot{V}_E$ (R^2 = 0.87) responses were shown to increase with WR throughout the exhaustive exercise test.

6.4.4 Comparison of physiological variables in relation to the RPE:

The coefficients of determination for the relationships (linear; curvilinear) between RPE (E-P scale; marbles) and various physiological variables ($\dot{V}O_2$; HR; $\dot{V}_E$) throughout the GXT are shown in Table 6.1. It is notable that the only significant differences were observed for the $\dot{V}O_2$ ($t_{(13)}$ = -3.416; P < 0.008) and HR ($t_{(13)}$ = -10.057; P < 0.008) with the marble response.

Table 6.1. Coefficients of determination for the relationships (linear; curvilinear) between RPE (E-P scale; marbles) and physiological variables ($\dot{V}O_2$; HR; $\dot{V}_E$) throughout the graded-exercise test.

	RPE: $\dot{V}O_2$	RPE:HR	RPE: $\dot{V}_E$	Marbles: $\dot{V}O_2$	Marbles:HR	Marbles: $\dot{V}_E$
Linear	R^2 = 0.85	R^2 = 0.90	R^2 = 0.90	R^2 = 0.76	R^2 = 0.72	R^2 = 0.81
Curvilinear	R^2 = 0.88	R^2 = 0.96	R^2 = 0.86	R^2 = 0.86*	R^2 = 0.92*	R^2 = 0.88

* Significantly (P < 0.008) stronger than the corresponding relationship (linear; curvilinear), for the same variable.

6.4.5 Hierarchical regression analysis:

All results of the hierarchical regression analyses are shown in Table 6.2. When the E-P scale was used to assess the RPE, HR (as the main IV) explained the largest proportion (63.7 %; P < 0.001) of the overall variance (66 %), with $\dot{V}O_2$ and $\dot{V}_E$ independently accounting for 48 % (P < 0.001) and 46.7 % (P < 0.001) of total variance, respectively. However, when RPE from the marble task was used as the DV, $\dot{V}_E$ accounted for the largest proportion (43.6 %) of the total variance (47 %) in RPE response ($P < 0.001$), with HR and $\dot{V}O_2$ accounting for 39.1 % ($P < 0.001$) and 36.9 % ($P < 0.001$), respectively.

6.4.6 RPE Exponents:

Average exponents of 2.22 (range: 1.10 – 3.75) and 3.14 (range: 1.79 – 4.62) were revealed for the E-P scale and marble task, respectively, with increasing work.

Table 6.2. Total- and partial variance in the RPE response (E-P scale & marble task) that is explained by individual physiological variables (oxygen uptake, $\dot{V}O_2$; heart rate, HR; ventilation, $\dot{V}_E$) using a hierarchical regression model.

			***R²* Change**		
DV	**IV Order of entry**	**Total Variance (%)**	**$\dot{V}O_2$ Variance (%)**	**HR Variance (%)**	**$\dot{V}_E$ Variance (%)**
E-P scale	$\dot{V}O_2$ / HR / $\dot{V}_E$	66 %	48.0*	17.9*	0.1
	$\dot{V}O_2$ / $\dot{V}_E$ / HR	66 %	48.0*	13.2*	4.8*
	HR / $\dot{V}O_2$ / $\dot{V}_E$	66 %	2.3*	63.7*	0
	HR / $\dot{V}_E$ / $\dot{V}O_2$	66 %	1.8*	63.7*	0.5
	$\dot{V}_E$ / $\dot{V}O_2$ / HR	66 %	6.1*	13.1*	46.7*
	$\dot{V}_E$ / HR / $\dot{V}O_2$	66 %	1.8*	17.5*	46.7*
Marbles	$\dot{V}O_2$ / HR / $\dot{V}_E$	47 %	36.9*	6.7*	3.3*
	$\dot{V}O_2$ / $\dot{V}_E$ / HR	47 %	36.9*	1.5	8.5*
	HR / $\dot{V}O_2$ / $\dot{V}_E$	47 %	4.6*	39.1*	3.3*
	HR / $\dot{V}_E$ / $\dot{V}O_2$	47 %	0.9	39.1*	7.0*
	$\dot{V}_E$ / $\dot{V}O_2$ / HR	47 %	1.9*	1.5	43.6*
	$\dot{V}_E$ / HR / $\dot{V}O_2$	47 %	0.9	2.5*	43.6*

* Significant additive contribution to the RPE response ($P < 0.05$)

6.4.7 Additional analyses:

An independent *t* test confirmed no significant differences ($P > 0.05$) in RPE response between children who rated using the E-P scale first, or those who rated using the marble task first ($R^2 = 0.95$ & $R^2 = 0.95$, respectively).

6.5 Discussion:

This study assessed the nature of the perceptual response of 7 – 8 year-old children during incremental, discontinuous treadmill exercise using two scaling methods; the E-P scale and a marble task. All children readily interpreted and utilised the E-P scale and marble task to assess their level of exertion across relative exercise stages, as demonstrated by the corresponding increases in physiological ($\dot{V}O_2$, HR and $\dot{V}_E$) and perceptual (E-P scale and marbles) data with increasing WR. The RPE increased linearly with WR ($R^2 = 0.96$) when assessed using the E-P scale, in contrast to a similar investigation (study 3). However, the high curvilinear R^2 values demonstrate the robustness of the E-P scale in allowing both linear and curvilinear growth functions in the RPE to be detected, which is in keeping with previous research (study 3). When the RPE was assessed by the marble dropping task, it is notable that the model which best described the change in perceived exertion with work rate was curvilinear ($R^2 = 0.94$). This concurs with observations from our previous study (study 3). The employment of the marble task alongside the E-P scale in this study was not intended to validate the E-P scale, but to provide a differing means (i.e. interval scaling cf. category-ratio scaling) of identifying the nature of perceptual responses in young children. In this regard, the findings of the marble task strengthen the notion that perceived exertion in young children (7 – 8 years) does not consistently increase in a linear fashion with increasing work, as is commonly presumed and documented in the literature.

6.5.1 Relationships between physiological and perceptual variables:

The supposition that ventilatory drive acts as the predominant mediator to the respiratory-metabolic signals of perceived exertion in young children, as in adults, provided the conceptual underpinning for the design of the E-P scale (Eston et al., 1994; Eston & Parfitt, 2007). In adults, moderately high correlations (r = 0.63 – 0.86) have been reported between the RPE and $\dot{V}_E$ (Chen et al., 2002; Coquart et al., 2009a). Although limited data exist on the relationship between the RPE and $\dot{V}_E$ in young children, Marinov et al. (2008) observed correlations of r = 0.51 – 0.59 and r = 0.62 – 0.64 between the RPE and $\dot{V}_E$ when using the Borg CR-10 scale (Borg, 1998) and the Pictorial CERT (PCERT; Yelling et al., 2002), respectively, across three trials of a continuous, incremental treadmill protocol, with children aged 10.4 (± 0.5) and 13.4 (± 0.5) years. In the previous study (study 3), a high average coefficient of determination (R^2 = 0.90) was reported for RPE (using the E-P scale) and $\dot{V}_E$ during discontinuous cycle ergometry exercise in an independent group of young children. The results from the current treadmill study are directly comparable to those from the latter study (R^2 = 0.90 & R^2 = 0.88 for E-P scale & marble task, respectively).

Interestingly, subsequent investigation into the relative contribution of $\dot{V}O_2$, HR or $\dot{V}_E$ to the perceptual response (E-P scale) revealed that the greatest proportion of the total variability in the RPE (66 %) was explained by HR and $\dot{V}O_2$ combined, not $\dot{V}_E$ as the underlying rationale to the E-P scale would suggest, nor as per the findings of study 3. In the marble task, however, $\dot{V}_E$ and HR accounted for the majority of the variance in the total RPE response (47 %). Such findings suggest that no one specific physiological variable is a predominant mediator of perceptual responses during treadmill exercise with young children. Indeed, in relation to the findings of study 3 during cycle ergometry exercise, the current study indicates that respiratory-metabolic cues emanating from all three of the main physiological processes investigated ($\dot{V}O_2$, HR,

$\dot{V}_E$), may significantly influence the overall RPE to varying degrees in young children, across differing exercise modalities.

6.5.2 Influence of age- and cognitive development on the perceptual response to exercise:

The E-P scale is a category scale with ratio properties; however, unlike other category-ratio scales (CR-10; Borg, 1998), free magnitude estimation above maximum (RPE 10) is not permitted. In this regard, the stage of cognitive development is important when applying the concept of perceived exertion in children (Eston, 2009b). The majority of perceived exertion research to-date has focussed on children aged 8 – 12 years, yet less attention has been paid to understanding the developmental steps in children aged 7-years (Groslambert & Mahon, 2006). As in study 3, the children in this study are within the ‘concrete operations’ period of cognitive development (7 – 11 years; Piaget, 1960). Although children are capable of ‘measuring’ by 7 – 8 years of age (Piaget, 1960), they find understanding fractions (ratios) difficult (Gelman & Williams, 1998). Moreover, at this stage children are unable to comprehend abstract concepts or hypothetical tasks, i.e. applying a number (particularly one obtained from a ratio construct) to a perceived level of exertion at an intensity which is higher than that ever ‘concretely’ experienced before. Thus, although a fixed-endpoint may provoke a ‘ceiling effect’ with adults, it may be necessary for children of this age (7 – 11 years).

6.5.3 Exponential nature of perceptual responses:

As the exponent for a straight line (representing a positive linear relationship between two variables) equates to a value of 1, any increase in an exponent will result in the line of ‘best fit’ between two variables increasing disproportionately and becoming curvilinear in appearance. In this regard, natural logarithmic values calculated between individual relationships of perceptual response and increasing work revealed average exponents of 2.22 and 3.14 for the E-P scale and marble task, respectively. This is in keeping with previous investigations that have yielded an exponent of 3 (in adults) for perceived exertion during treadmill walking / running (Borg, 1973, 1998). Exponents of 1.03 (± 0.68) and 1.30 (± 0.83) for the E-P scale and marble task, respectively, have been observed previously during cycling exercise (study 3), similar to the average exponent (of 1.6) often associated with short-term perceived exertion during cycle ergometry exercise (Borg, 1998; Borg & Dahlström, 1959). The combined findings of this study and study 3 indicate that the rate of change in the RPE of young children may occur in relation to exercise modality, rather than as a function of the exercise mode which is depicted in the E-P scale. This infers that specifically-designed pictorial ratings scales may not be necessary for differing exercise tasks, in accordance with previous observations (study 3; Parfitt et al., 2007).

6.5.4 Terminal ratings of perceived exertion during maximal treadmill exercise:

It is notable that the average terminal RPE at exhaustion was 9.7 on the E-P scale and 49.0 when using the marble task. These were not statistically different to the theoretical maximal values of both ratings methods (E-P: 10; Marbles: 50). Conversely, previous studies involving children have reported terminal RPE values that were lower than the theoretical maximum at point of exhaustion (study 3; Barkley & Roemmich, 2008), although the difference between the terminal RPE reported in study 3 (9.4 ± 1.1) and the current study is negligible.

6.6 Conclusion:

The E-P scale is robust in its ability to detect both linear and curvilinear growth functions in the RPE during treadmill running. Similar perceptual growths functions were observed using a distinct interval scaling method (marble dropping task), strengthening the notion that perceived exertion in young children (7 – 8 years) does not consistently increase in a linear fashion with increasing work. Further research is necessary to elucidate the probable mediators of effort sense in young children. Future research may be warranted to assess the influence of familiarisation on trial-to-trial variability of perceived exertion responses in children of this age.

Chapter 7

Study 5

Prediction of maximal oxygen uptake from the ratings of perceived exertion in children, aged 7 – 8 years: efficacy of the Eston-Parfitt RPE scale.

7.1 Abstract:

This study assessed the efficacy of the E-P scale in obtaining accurate predictions of $\dot{V}O_2$max in young healthy children, aged 7 – 8 years, during cycle ergometry and treadmill exercise. Submaximal RPE and $\dot{V}O_2$ data collated from two previous studies in this thesis (studies 3 & 4) were employed to obtain estimates of $\dot{V}O_2$max from two submaximal intensities (RPE 5 and 7), using two extrapolation methods: linear and curvilinear. Results of this study were equivocal with regards to the accuracy in predicting $\dot{V}O_2$max. Yet on the basis of the Limits of Agreement analyses, the use of the RPE for predicting $\dot{V}O_2$max in children of this age is not recommended.

7.2 Introduction:

As has previously been discussed in the review of literature, and studies 1 and 2, the RPE are a valid and reliable means to estimate an individual's maximal aerobic capacity. Accurate predictions of maximal oxygen uptake ($\dot{V}O_2$max) have been obtained via linear regression analysis using the submaximal $\dot{V}O_2$ values equating to differing levels of exertion during various exercise protocols (studies 1 & 2; Coquart et al., 2009b; Davies et al., 2008; Eston et al., 2005, 2006, 2008; Faulkner & Eston, 2007; Faulkner et al., 2007; Morris et al., 2009). This has been demonstrated during estimation procedures utilising either a graded-exercise test (GXT; study 1; Faulkner & Eston, 2007) or a continuous ramp-incremental protocol (study 2), or when the exercise test itself has been guided by the RPE (production protocol; study 1; Eston et al., 2005, 2006, 2008; Faulkner et al., 2007; Morris et al., 2009). More accurate predictions have been demonstrated when the submaximal $\dot{V}O_2$ is extrapolated from a higher perceptual range (Eston et al., 2005, 2006, 2008; Faulkner & Eston, 2007; Faulkner et al., 2007), or following familiarisation (Davies et al., 2008; Eston et al., 2005, 2008; Faulkner & Eston, 2007; Faulkner et al., 2007; Morris et al., 2009). However, suitable estimates have also been obtained from a single, low-moderate estimation protocol in healthy low-fit men and women (studies 1 & 2).

Despite the significant amount of literature assessing the predictive utility of the RPE with adults, research in this area is yet to be conducted with children. Several studies have demonstrated that children possess the ability to rate their perception of exertion accurately across differing intensities and modes of exercise (studies 3 & 4; Lamb et al., 2008). Therefore, it is feasible to consider that the estimates of exertion obtained during discontinuous, incremental exercise with young children may also be utilised to predict the $\dot{V}O_2$max with acceptable accuracy, as is consistently observed with adults.

7.2.1 Purpose and hypothesis:

The purpose of this study was to assess the utility of the E-P scale in providing accurate predictions of $\dot{V}O_2$max in young healthy children, aged 7 – 8 years, during cycle ergometry and treadmill exercise. It was hypothesised that accurate predictions of $\dot{V}O_2$max would be obtained from both an RPE 5 and 7, according to the E-P scale, regardless of whether linear- or curvilinear extrapolation was employed.

7.3 Method:

7.3.1 Participants:

Physiological and perceptual data obtained from 29 participants who took part in studies 3 and 4 were utilised for the purpose of this study. As the focus of this investigation differed from that of the preceding studies but required equivalent data for the purpose of estimating $\dot{V}O_2$max, the previously collated data were utilised in the current study without warranting any further experimental procedures to be conducted. As such, no further ethical considerations were necessary over and above those implemented in both studies 3 and 4.

7.3.2 Procedures:

All $\dot{V}O_2$ and RPE data collated on the participants from study 3 (n = 15) and study 4 (n = 14) were used in the subsequent analyses.

a) Prediction of $\dot{V}O_2$max via linear regression analysis:

Young children may perceive exercise effort in both a linear or curvilinear fashion in relation to the true intensity of effort (i.e. WR, $\dot{V}O_2$), during both cycle ergometry (study 3) and treadmill exercise (study 4). As such, the subsequent analyses utilised both linear- and curvilinear relationships in order to obtain predictions of $\dot{V}O_2$max during cycling and treadmill exercise. Firstly, a simple linear regression analysis was employed on the submaximal RPE and $\dot{V}O_2$ values, up to- and including both an RPE of 5 and 7 for each participant, to obtain a prediction of $\dot{V}O_2$max (*linear*). An RPE of 5 (“Starting to get hard”) and 7 (“Very hard”) on the E-P scale were chosen to represent a similar feeling of exertion to those frequently utilised in adult research when employing the Borg 6-20 scale, that of an RPE 13 (“Somewhat hard”) or 17 (“Very hard”). However, inferring that the relationship between these two variables is in fact curvilinear in nature, the submaximal RPE and $\dot{V}O_2$ values (≤ RPE of 5 & 7) for each participant were additionally log-transformed, and then linearly regressed to obtain an appropriate exponent (*b* coefficient) and constant which could be used to predict $\dot{V}O_2$max using the following equation: y = bx + c; where ‘y’ is the dependent variable (ln$\dot{V}O_2$), ‘*b*’ is the beta coefficient, ‘x’ is the independent variable (maximal RPE [10]), and 'c' is the constant. Logged variables were then transformed into their inverse to obtain a prediction of $\dot{V}O_2$max for each individual (*curvilinear*).

7.3.3 Data Analysis:

a) Comparison between measured- and predicted $\dot{V}O_2$max:

As $\dot{V}O_2$max is known to be greater during treadmill running than during cycle ergometry (Cooke, 2009), two one-factor repeated measures ANOVA were used to compare the linear- and curvilinear predictions of $\dot{V}O_2$max from both an RPE 5 and 7, to measured $\dot{V}O_2$max during both exercise tasks. If sphericity was not assumed according to the Mauchly test, the Greenhouse-Geisser epsilon correction factor was applied to correct the degrees of freedom of the F ratio. Alpha was set at 0.05 and adjusted accordingly.

b) Measures of agreement:

A Bland and Altman (1986) 95 % limits of agreement (LoA) analysis was utilised to quantify the agreement (bias & random error) between measured- and predicted $\dot{V}O_2$max (from RPE 5 & 7).

7.4 Results:

All descriptive data concerning the nature of the participants from which these data were collated and subsequently analysed can be seen in studies 3 and 4. A paired-samples t test confirmed the belief that treadmill exercise elicits higher $\dot{V}O_2$max values than cycle ergometry ($t_{(27)} = -3.72$, $P < 0.01$). As such, all further analyses have been divided into separate exercise modes.

7.4.1 Comparison between measured- and predicted $\dot{V}O_2max$ during cycle ergometry:

Repeated-measures ANOVA demonstrated a significant difference ($F_{(1.4,\ 19.0)}$ = 13.55, $P < 0.05$) between measured- (39.1 ± 7.7 ml·kg^{-1}·min^{-1}) and predicted $\dot{V}O_2$max from an RPE 5 when extrapolated using either the *linear* or *curvilinear* model (53.4 ± 17.2 ml·kg^{-1}·min^{-1} & 48.4 ± 17.0 ml·kg^{-1}·min^{-1}, respectively), during cycle ergometry. Post-hoc *t* tests revealed that the prediction from an RPE 5, using both linear- and curvilinear extrapolation, significantly overestimated ($P < 0.016$) measured $\dot{V}O_2$max ($t_{(14)} = -4.46$ & $t_{(14)} = -2.85$, respectively). Similarly, a significant difference ($F_{(1.1,\ 15.8)} = 8.20$, $P < 0.05$) was also noted between measured- and predicted $\dot{V}O_2$max from an RPE 7 using either the *linear* or *curvilinear* model (47.8 ± 13.1 ml·kg^{-1}·min^{-1} & 45.0 ± 15.4 ml·kg^{-1}·min^{-1}, respectively). A paired *t* test demonstrated that linear extrapolation from an RPE 7 also resulted in an overestimation of measured $\dot{V}O_2$max ($t_{(14)} = -3.95$, $P < 0.016$), whereas, no statistical difference ($P > 0.016$) was noted between measured- and predicted $\dot{V}O_2$max using the curvilinear method from an RPE 7 (Figure 7.1).

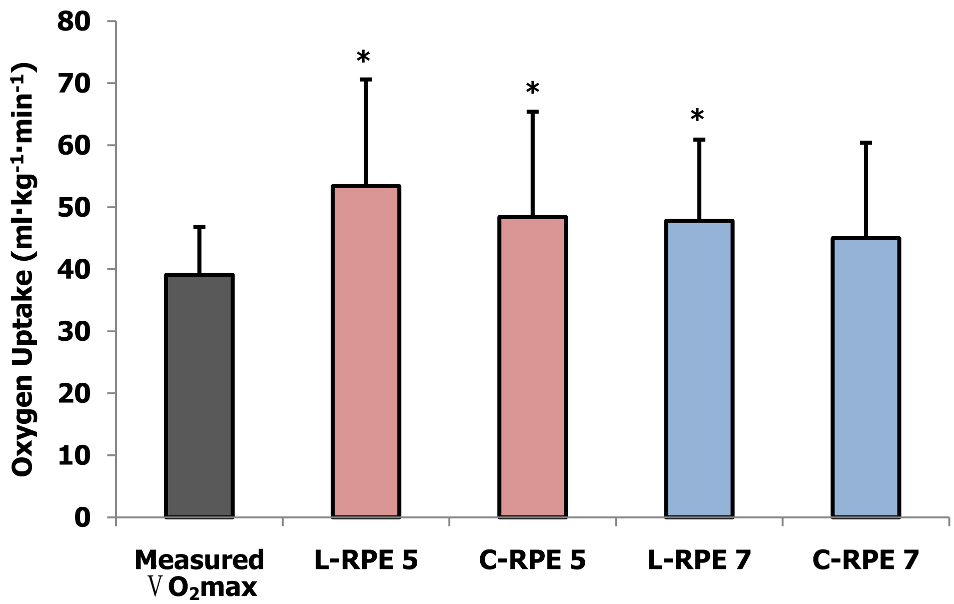

Figure 7.1. Measured- and predicted $\dot{V}O_2$max from an RPE of 5 and 7, using both linear (L-RPE 5; L-RPE 7) and curvilinear (C-RPE 5; C-RPE 7) extrapolation during cycle ergometry. Values are mean ± SD.

* Significant difference (P < 0.016) between measured- and predicted $\dot{V}O_2$max.

7.4.2 Comparison between measured- and predicted $\dot{V}O_2$max during treadmill exercise:

During treadmill exercise, a significant difference ($F_{(2, 24)} = 6.11$, $P < 0.05$) was observed between measured- (51.5 ± 6.8 ml·kg^{-1}·min^{-1}) and predicted $\dot{V}O_2$max from an RPE 5 when extrapolated using either the *linear* or *curvilinear* model (61.0 ± 14.0 ml·kg^{-1}·min^{-1} & 59.6 ± 16.8 ml·kg^{-1}·min^{-1}, respectively). Post-hoc *t* tests revealed that the linear model significantly ($t_{(12)} = -3.23$, $P < 0.016$) overestimated measured $\dot{V}O_2$max. Predictions from an RPE 5 using the curvilinear model however were not statistically different to measured values ($P > 0.016$). Similarly, no significant differences ($P > 0.05$) were apparent between measured- and predicted $\dot{V}O_2$max from an RPE 7 using either the *linear* or *curvilinear* model (51.4 ± 12.9 ml·kg^{-1}·min^{-1} & 50.0 ± 13.2 ml·kg^{-1}·min^{-1}, respectively; Figure 7.2).

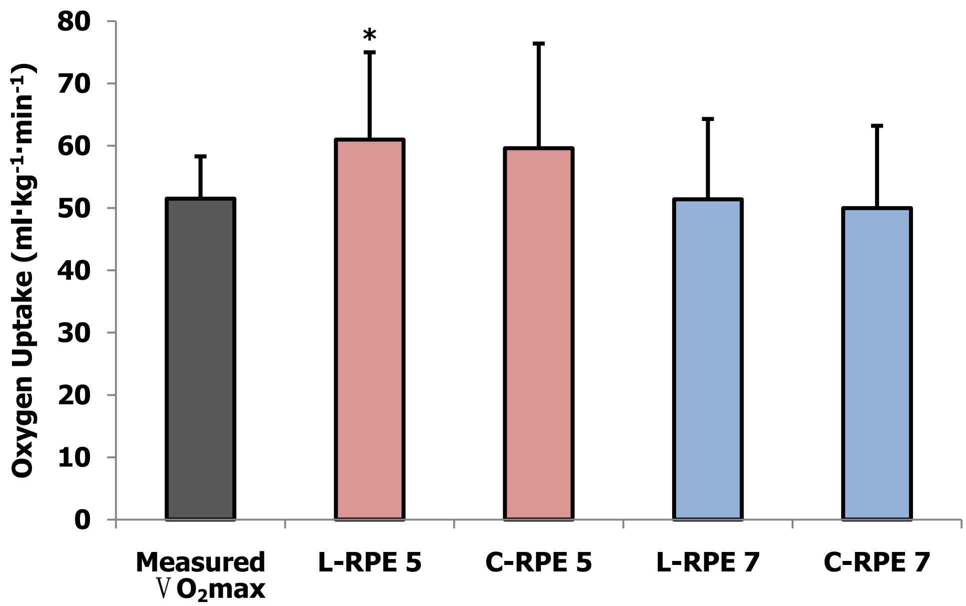

Figure 7.2. Measured- and predicted $\dot{V}O_2$max from an RPE of 5 and 7, using both linear (L-RPE 5; L-RPE 7) and curvilinear (C-RPE 5; C-RPE 7) extrapolation during treadmill exercise. Values are mean ± SD.

* Significant difference ($P < 0.016$) between measured- and predicted $\dot{V}O_2$max.

7.4.3 Consistency of $\dot{V}O_2$max predictions:

The 95 % LoA between measured- and predicted $\dot{V}O_2$max from an RPE 5 and 7, using either *linear* or *curvilinear* extrapolation, during both cycle ergometry and treadmill exercise, are shown in Table 7.1. As shown, the mean bias demonstrated for each predictive method was lower during treadmill exercise than during cycle ergometry, regardless of whether linear or curvilinear extrapolation was utilised. Furthermore, it is evident that a better agreement may be obtained between measured- and predicted $\dot{V}O_2$max when extrapolating from a higher perceptual range (RPE 7 cf. RPE 5), regardless of exercise mode.

Table 7.1. The 95 % LoA between measured- and predicted $\dot{V}O_2$max from an RPE 5 and 7, using either linear (L-RPE 5; L-RPE 7) or curvilinear (C-RPE 5; C-RPE 7) extrapolation, during both cycle ergometry and treadmill exercise. Values are mean bias ± random error ($ml \cdot kg^{-1} \cdot min^{-1}$).

	L-RPE 5	C-RPE 5	L-RPE 7	C-RPE 7
Cycle Ergometry	14.4 ± 24.5	9.4 ± 24.9	8.7 ± 16.7	5.9 ± 22.1
Treadmill	9.5 ± 20.7	8.0 ± 24.9	1.3 ± 15.1	-0.2 ± 15.6

7.5 Discussion:

The purpose of this study was to assess the efficacy of the E-P scale in obtaining accurate estimates of $\dot{V}O_2$max in young children, aged 7 – 8 years. The current study demonstrated that of the eight submaximal RPE prediction methods tested, four (three treadmill & one cycle) provided estimates of $\dot{V}O_2$max that were not significantly different from the measured value. It is noteworthy however that an equivalent number of methods of predicting $\dot{V}O_2$max were shown to be inaccurate using both linear- and curvilinear extrapolation procedures, according to the statistical analyses employed in this study.

7.5.1 Appraisal of the predictions of $\dot{V}O_2$max using the E-P scale:

Predictions were obtained from two effort levels; that which equated to a feeling of "Starting to get hard" (RPE 5) or a "Very hard" feeling (RPE 7), according to the E-P scale. Generally, predictions were more accurate during treadmill exercise than during cycle ergometry, and more reliable when extrapolated from a higher perceptual range (RPE 7 cf. RPE 5). There was no clear indication as to whether linear or curvilinear extrapolation proved a more reliable means of obtaining $\dot{V}O_2$max predictions in this study, although the linear models tested overestimated $\dot{V}O_2$max on more occasions than did the curvilinear models tested. As, at times, both linear and curvilinear extrapolation proved effective in providing estimates of $\dot{V}O_2$max that were not dissimilar to measured values, it provides further indication that a child's perception of exertion may rise according to a positive function in relation to increasing exercise intensity. As such, in an exercise setting, it would be prudent for researchers and practitioners to not simply assume the presence of a linear relation but consider the curvilinear properties of the RPE when obtaining perceptual ratings from children of this age.

As expected, treadmill running elicited higher measured $\dot{V}O_2$max values then cycle ergometry exercise. The current study utilised an estimation protocol to obtain predictions of $\dot{V}O_2$max using the submaximal RPE in children. To some extent, the findings of this study concur with previous research that has employed the Borg 6-20 RPE scale with adults. For example, study 1 of this thesis demonstrated that extrapolation of submaximal $\dot{V}O_2$ values, prior to- and including an RPE 13, from a passive estimation procedure may provide accurate predictions of $\dot{V}O_2$max during a single, low-moderate exercise session in men and women of low-fitness. Similarly, Faulkner & Eston (2007) have shown no differences between measured- and predicted $\dot{V}O_2$max from an overall RPE of 13, 15 or 17, during a graded-exercise test on a cycle ergometer with high- and low-fit men and women. In this study, statistically accurate predictions of $\dot{V}O_2$max were also obtained, in some instances (4 of 8), from the RPE estimated during a single exercise session on either a cycle ergometer or treadmill for an equivalent exercise intensity (RPE 5 or 7). However, it is important to note that large discrepancies in $\dot{V}O_2$max estimations were simultaneously observed using these techniques, particularly when extrapolated from a lower perceptual range (i.e. RPE 5).

7.5.2 Implications of the limits of agreement (LoA):

Despite the fact that half of the methods of $\dot{V}O_2$max prediction tested in this study gave values that were not statistically different to measured $\dot{V}O_2$max (according to ANOVA), the corresponding 95 % LoA analyses revealed stark findings with regards to the potential utility of the E-P scale for estimating $\dot{V}O_2$max in children. In this regard, the wide LoA observed between measured- and predicted $\dot{V}O_2$max during cycle ergometry suggest that $\dot{V}O_2$max may be vastly overestimated in children, regardless of whether linear of curvilinear extrapolation is used. This overestimation equates to a margin of error in prediction that may range between 65 – 100 %, in best- and worst case scenario. Although slightly improved over cycle ergometry, similar findings were noted for treadmill exercise with a margin of error between 31 – 64 % associated with estimates of $\dot{V}O_2$max. Thus, it is important to recognise that although the mean data may imply that predictions are *accurate* during cycle ergometry and treadmill exercise, consideration of the consistency of these predictions in relation to measured values is essential. With adults, previously reported LoA analyses have demonstrated a 27 – 29 % error in the prediction of $\dot{V}O_2$max from both an RPE 13 and 15, during an estimation GXT (study 1; Coquart et al., 2009; Faulkner & Eston 2007), and 20 – 21 % error from a continuous, ramp-incremental protocol (study 2). As a lower margin of error is favourable in the prediction of $\dot{V}O_2$max, the LoA in the current study, particularly during cycle ergometry, may be deemed unacceptable. Although predictions from an RPE 7 were slightly more encouraging, it would be prudent to acknowledge that these LoA still represent a significant margin of error in the estimate of $\dot{V}O_2$max. Nevertheless, it is noteworthy that more accurate $\dot{V}O_2$max predictions may be obtained from a higher perceptual range (i.e. up to an RPE 7) in children, which is in keeping with previous research in adults (Eston et al., 2005, 2006, 2008; Faulkner & Eston, 2007; Faulkner et al., 2007; Morris et al., 2009).

7.6 Conclusion:

Consequently, on the basis of these preliminary findings, accurate prediction of $\dot{V}O_2$max using the E-P scale during dynamic exercise with children aged 7 – 8 years at this stage cannot be verified. If unreliable estimates of $\dot{V}O_2$max were calculated using this method and subsequently employed during succeeding exercise, for example, utilised as the basis to structure the intensity of an exercise session, this may result in a child exercising at a higher intensity than that originally prescribed. The repercussions of such an overexertion may be a lack in future exercise adherence (Parfitt et al., 1994). It is highly recommended that further research in this area be undertaken to assess the utility of the E-P scale in predicting $\dot{V}O_2$max in children, however a larger sample size would be advocated in a subsequent study. Future research is recommended in this area to assess the age- and developmental level of the children, exercise experience, and mode of exercise as factors affecting the accuracy of predictions.

Chapter 8

Study 6

Do children employ pacing strategies during field-based exercise?

8.1 Abstract:

This study assessed whether young, untrained children (aged 9 – 11 years) utilise pacing strategies during an 800 m running event in order to complete the distance in the fastest possible time. This study also assessed whether exercise experience and task familiarisation facilitated improvements in performance times, and to what extent the added element of competition influenced overall exercise performance. All participants completed a graded-exercise test to exhaustion on a treadmill (laboratory trial), three 800 m runs individually on an outdoor athletics track (field trials 1 to 3), and one 800 m run in small groups (field trial 4; competition). The findings demonstrated that children employ pacing strategies during a structured exercise event, despite having no prior experience of the given exercise task. Nevertheless, familiarisation was shown to enhance performance times across trials 1 to 3 ($P < 0.017$). The time taken to complete the 800 m run during the competitive trial (260.5-s), in comparison to the third (and best) individual trial (242.4-s), was approaching significance ($P = 0.06$). The results further suggested that perceived exertion may differ between laboratory and field-based exercise tasks, for a given physiological cost. Future research is warranted to distinguish the ‘optimal’ pacing strategy for a given exercise event with children, and to evaluate the specific factors that influence the pacing strategy adopted, and thus overall performance, during a competitive situation.

8.2 Introduction:

Individuals often regulate their work output (pacing strategy) during endurance exercise to ensure that an athletic event is completed successfully, in the fastest possible time (Foster et al., 1993, 1994; Foster, Hoyos, Earnest, & Lucia, 2005; St Clair Gibson et al., 2006). Research suggests that the chosen pacing strategy may be dependent upon a number of situational factors, including the distance and duration of the event, environmental conditions, mode of exercise, and degree of competition, in addition to the individual's level of motivation, knowledge and athletic experience (Ansley et al., 2004a, 2004b; Bishop, Bonetti, & Dawson, 2002; de Koning, Bobbert, & Foster, 1999; Foster et al., 1993, 1994; Kay et al., 2001; Mattern, Kenefick, Kertzer, & Quinn, 2001; Rauch et al., 2005; St Clair Gibson et al., 2006). Yet, despite the fact that the relative influence of each of the aforementioned variables on a given pacing strategy relies on prior learning, no studies have assessed the importance of age- and cognitive development in the process of forming an appropriate pacing strategy. Furthermore, relevant empirical studies have largely assessed the applicability of pacing strategies with athletic adults, within a laboratory environment, and to date, research examining the pacing strategies employed during competition is scarce (Atkinson & Edwards, 1998).

8.2.1 Pacing in relation to the theoretical models of fatigue:

Recent theoretical models have been proposed which endeavour to elucidate the mechanisms associated with the development of a pacing strategy and the avoidance of premature fatigue. The teleoanticipation and central governor models of fatigue illustrate how the brain may regulate exercise work rate through the integration of numerous signals from various peripheral physiological systems (for review see 2.9.2 – 2.9.3). Although theoretically driven, these models are borne out of observations of the responses of athletic adults to excessive exercise. Limited scientific evidence exists to infer that these models may be relevant to the exercising child. It is noteworthy however that as a child's muscle tissue is in the process of growth and development, excessive exercise may impose more damage on their immature musculoskeletal and cardiopulmonary systems than would a comparative overexertion in adults (Rowland, 2004). Thus, it is feasible that children may possess a protective limiting control mechanism, in accordance with the central governor model currently proposed with adults, which acts specifically to prevent any harmful physiological disturbances. Accordingly, like adults, children may adopt pacing strategies to appropriately regulate their exercise intensity. However, no empirical evidence exists to support this assumption.

8.2.2 Pacing in relation to the RPE:

It has been proposed that the ratings of perceived exertion (RPE) are a key component of a regulatory system that exists to protect the body from potential bodily harm, which may occur as a result of exercising for too long or too hard (Tucker, 2009). Specifically, it is suggested that the RPE may mediate the anticipatory regulation of exercise, or pacing strategy adopted during an exercise bout. Previous research, including studies 3 and 4 of this thesis, has demonstrated that children can accurately gauge their level of exertion using perceptual ratings scales (Barkley & Roemmich, 2008; Lamb, 1995; Parfitt et al., 2007; Robertson et al., 2000a; Roemmich et al., 2006). Yet, this has primarily been shown within a laboratory setting. Limited research has assessed the utility of the ratings of perceived exertion (RPE) for assessing exercise effort during field-based exercise.

8.2.3 Purpose and hypotheses:

The purpose of this study was therefore to assess whether children employ pacing strategies during endurance running on an outdoor athletics track, and to examine the influence of level of competition on any adopted pacing strategy. It was hypothesised that children would employ an appropriate pacing strategy throughout the running event and that this would improve with trial familiarisation. It was also hypothesised that any previously learned pacing strategy would be detrimentally influenced by the addition of a level of competition.

8.3 Method:

8.3.1 Participants:

Thirteen healthy children (n = 8 boys; age: 10.3 ± 0.7 y; height: 1.43 ± 0.10 m; body mass: 34.0 ± 7.5 kg; n = 5 girls; age: 10.6 ± 0.5 y; height: 1.44 ± 0.03 m; body mass: 34.8 ± 5.7 kg) volunteered for the study. Participants were recruited using information sheets (Appendices 1g & 1h) from two local schools in the Exeter area. All children were asymptomatic of illness or disease and free from injury, as assessed by a standardised health questionnaire which was completed by parents / guardians (Appendix 9). Informed consent (Appendix 2g) and assent (Appendix 2h) were obtained from parents / guardians and children, respectively, prior to the start of the study. All participants were generally active (according to self-reports and parental-reports of activity status) however no child was specifically trained in any particular sport. This study was conducted in accordance with the ethical guidelines, as laid out by the Ethics Committee of the School of Sport and Health Sciences at the University of Exeter.

8.3.2 Procedures:

All participants took part in five exercise sessions. The initial session was laboratory-based, comprising basic anthropometric measurements, including height and body mass (SECA, Hamburg, Germany), and a graded-exercise test (GXT) to volitional exhaustion on a motorised treadmill (Woodway GmbH PPS 55Med-I, Weil am Rhein, Germany) to obtain maximal physiological (maximal oxygen uptake: $\dot{V}O_2max$; heart rate max: HRmax) and perceptual (RPE) criteria. This session simultaneously served as a habituation to the use of the E-P scale for providing perceptual ratings during dynamic exercise, in addition to familiarising the children with the equipment (HR monitor and watch) to be used in subsequent sessions. Respiratory gases ($\dot{V}O_2$, $\dot{V}_E$, RER) were continuously measured using breath-by-breath sampling (Cortex Metalyzer II, Biophysik, Leipzig, Germany) via a large paediatric facemask (Hans Rudolph Inc., Kansas City, USA). The gas analysis system was calibrated prior to each test according to the manufacturers guidelines, with ambient air measurements calibrated against known concentrations of gas, and volume calibrations performed using a 3-litre syringe (Hans Rudolph Inc., Kansas City, USA). A paediatric wireless chest strap telemetry system (Wearlink+, Polar Electro Oy, Kempele, Finland) was used to record heart rate throughout the GXT. Physical and physiological data were masked from participants at all times. The four subsequent exercise sessions were field-based and took place on an outdoor grass athletics pitch (see section 8.3.4).

8.3.3 Laboratory-based GXT to volitional exhaustion:

Prior to the commencement of the GXT, participants were habituated to the treadmill at speeds of 4, 6, and 8 km·h^{-1}, as these were the speeds to be used in the subsequent GXT. Participants were then provided a short rest period wherein standardised instructions for the use of the E-P scale (as per study 4) were provided. Any questions as to the nature of the GXT or to the use of the E-P scale were resolved during this time. The GXT was continuous in nature, with 1-min bouts of exercise succeeding each increment in work. The test initiated at a speed of 4 km·h^{-1} at 0 % gradient and increased in speed by 2 km·h^{-1} for the 2 subsequent 1-min bouts of exercise. Thereafter (8 km·h^{-1}; 0 %), speed remained unchanged whilst gradient increased by 2 % for each active bout until $\dot{V}O_2$max. Participants rated their perception of exertion in the final 10-s of each active bout of exercise. The E-P scale was place directly in front of each participant and the question '*how hard does the exercise feel to* *you?*' was asked by the experimenter. Children proceeded to point to- or state a number or phrase that best described their current level of exertion. The value was noted, and the treadmill speed or gradient was then adjusted accordingly to induce an increase in work rate. Time taken to adjust the treadmill between stages was ≤ 10-s for each participant, and timing of the succeeding 1-min active bout commenced once this adjustment was complete.

Criteria for terminating the exercise test included exhaustion, in association with a HR approximating 200 b·min^{-1}; respiratory exchange ratio (RER) ≥ 1.00; an evident plateau or peak in $\dot{V}O_2$, or < 2.1 ml·kg^{-1}·min^{-1} increase in $\dot{V}O_2$ in the final stage of exercise (Rowland, 1996; Stratton & Williams, 2007).

8.3.4 Field-based exercise tests:

A marked grass athletics track of 300 m was used for the subsequent exercise sessions. Each participant was required to run a distance of 800 m in the fastest time possible around the athletics track, which equated to 2 $^{2}/_{3}$ laps, on four separate days. During the first 3 of these 4 exercise sessions, participants ran the 800 m distance individually. Participants were encouraged at the start of each test to run the 800 m distance 'as fast as possible'; however, no verbal encouragement was provided throughout the test. Markers were placed at each 200 m point around the track, and at both the start and finish lines. These markers were clearly visible to each participant for the duration of the test. The time taken for participants to complete the 800 m distance, as well as 200 m split times were recorded during each test. Each participant wore a heart rate monitor and watch which continuously measured and recorded HR in 5-s bins, for the duration of the test. Enlarged versions of the E-P scale (size A0) were additionally placed at each 200 m marker around the track. As children ran past each marker, they provided a current rating of perceived exertion by clearly stating a corresponding number to the experimenter who was holding the enlarged scale (Figure 8.1).

Figure 8.1. Participant performing the 800 m run during an individual field trial.

All procedures during the fourth (competition) test were identical to the previous three tests with one exception; during this test, participants ran the 800 m distance in small groups of either 4 or 5. As in the previous three trials, each child provided their RPE at each 200 m marker throughout the test (Figure 8.2). Standardised instructions as to the use of the E-P scale were repeated prior to each exercise test. No feedback as to completion times or any physiological data were provided until the completion of all tests.

Figure 8.2. Participants performing the 800 m run during the group field trial.

8.3.5 Data analysis:

a) Physical (time), physiological (HR; %HRmax), and perceptual responses across distance:

A series of repeated-measures analysis of variance (ANOVA) were used to assess the total time to complete each 800 m distance, as well as the average split times, absolute and relative (%HRmax) HR, and RPE between each 200 m distance, across the first three field-based exercise trials. If assumptions of sphericity were violated according to the Mauchley's test, a Greenhouse-Geisser correction factor was applied to correct the degrees of freedom of the *F* ratio. Post-hoc *t* tests were employed where statistical differences were observed, with Bonferroni adjustment to increase the stringency of the analysis and to protect against type I error.

b) Comparison of individual- and group responses:

With the exception of total time that required the employment of a paired samples *t* test, ANOVA was similarly employed to examine the differences in the aforementioned variables between the third *individual* trial (which equated the 'best' trial in terms of completion time) and the fourth *group* (competition) trial. Post-hoc *t* tests (with Bonferroni adjustment) were also employed where appropriate.

c) Comparison of RPE responses at equivalent intensities across conditions (GXT cf. field-trial):

The average RPE and corresponding average relative HR recorded at each 200 m mark across the first three field trials were used to assess the reliability of the RPE across conditions (i.e. laboratory GXT cf. field-based exercise). An average HR for each 200 m distance was calculated across the three field-trials, for each individual. Linear regression analysis was then conducted for each individual using collated submaximal HR and RPE responses reported during the GXT. This was to obtain the RPE values from the GXT which correspond to the average HR recorded at each 200 m distance during the field-trials. The RPE (for both the GXT and field-trials) were then analysed for differences across conditions using paired-sample *t* tests.

8.4 Results:

Maximal physiological and perceptual data collated during the GXT were (mean ± SD) $\dot{V}O_2$: 49.8 ± 8.7 $ml \cdot kg^{-1} \cdot min^{-1}$; HR: 208 ± 5 $b \cdot min^{-1}$; RER: 1.21 ± 0.09; RPE: 8.4 ± 1.2.

8.4.1 Total time to complete 800 m, across three trials:

Repeated-measures ANOVA demonstrated a significant difference between the total time to complete field trials 1 to 3 ($F_{(2,\ 24)}$ = 5.541, P = 0.01). Post-hoc t tests revealed that the total time to complete trials 2 (243.5 ± 51.2-s) and 3 (242.4 ± 51.5-s) were both significantly faster ($t_{(12)}$ = 2.813 & $t_{(12)}$ = 2.745, respectively; P = 0.017) than trial 1 (250.1 ± 50.4-s). However, no difference was observed between trials 2 and 3 (P > 0.017; Figure 8.3).

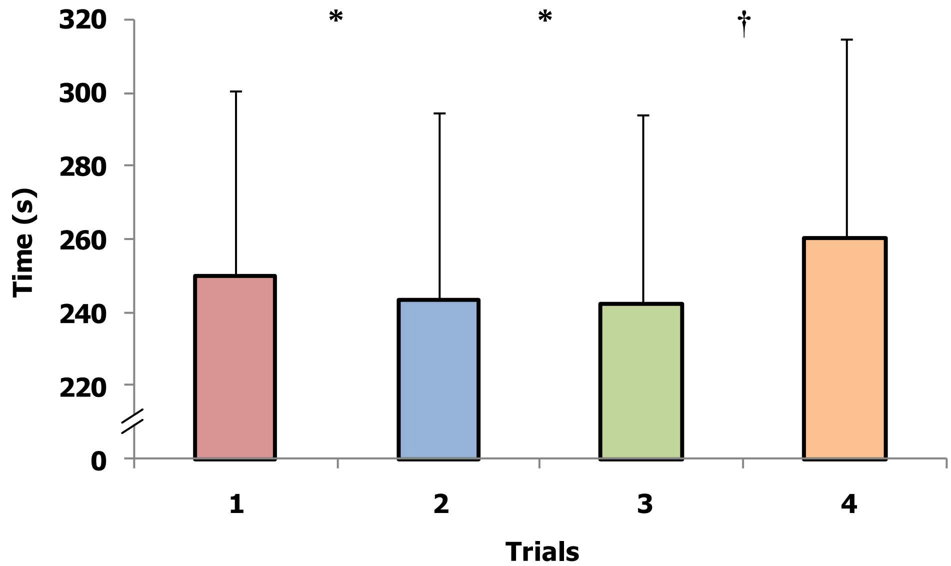

Figure 8.3. Total time (s) to complete each 800 m distance, across all field trials (1 to 4). Values are mean ± SD.

* Significant difference (P = 0.017) in total time to complete trials 1 and 2, and trials 1 and 3.

† Approaching significance (P = 0.06) between trials 3 and 4.

8.4.2 Split times over 800 m, across three trials:

ANOVA revealed a significant difference between the split times of each 200 m mark ($F_{(3,\ 36)}$ = 33.689, P < 0.001) across trials 1 to 3 ($F_{(2,\ 24)}$ = 5.360, P < 0.05), but no interaction was observed (P > 0.05). Average split time to complete the first 200 m of the event (53.1 ± 12.2-s) was significantly faster ($t_{(38)}$ = -11.679, P < 0.008) than the second 200 m (400 m; 65.3 ± 13.3-s), and the average split time to complete the final 200 m (800 m; 61.9 ± 11.8-s) was significantly faster ($t_{(38)}$ = 3.344, $P < 0.008$) than the third 200 m (600 m; 65.1 ± 14.8-s). There was no difference in split times between 400 m and 600 m, however ($P > 0.008$). Further *t* tests also revealed that the average split times for trial 1 were significantly slower (62.5 ± 13.9-s; $t_{(51)}$ = 2.620, $P < 0.017$) than trial 3 (60.6 ± 13.6-s) however no difference was observed between trials 1 and 2 (60.9 ± 14.3-s, for trial 2), or trials 2 and 3 ($P > 0.017$; Figure 8.4).

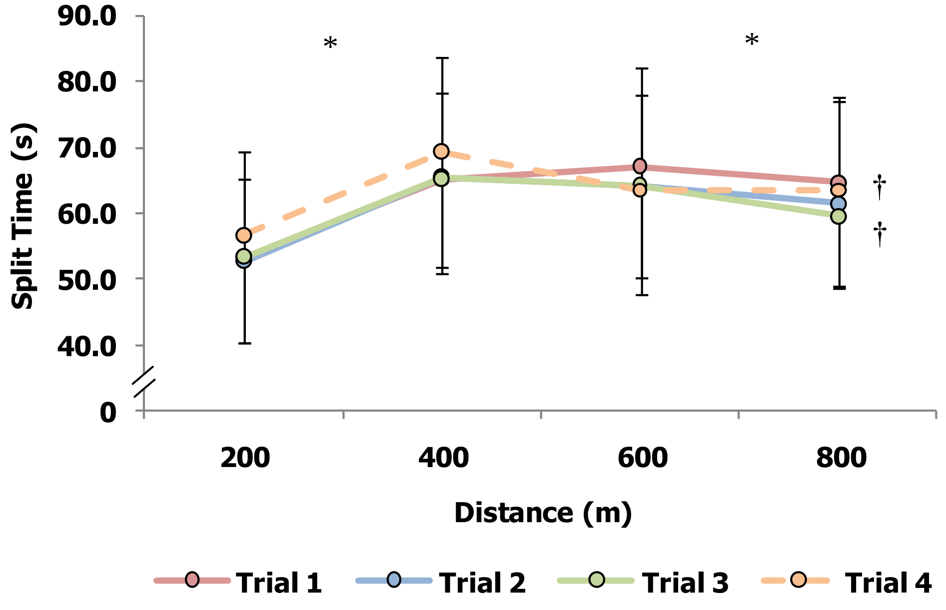

Figure 8.4. Split times (s) of each 200 m distance, across all field trials (1 to 4). Values are mean ± SD.

* Significant difference ($P < 0.008$) in split times of the first 200 m and 400 m (trials 1 to 4), and split times for 600 m and 800 m (trials 1 to 3).

† Significant difference ($P < 0.017$) in average split times across trials 1 and 3, and trials 3 and 4.

8.4.3 Absolute & relative heart rate over 800 m, across three trials:

Average HR was significantly different across each 200 m mark ($F_{(1.8,\ 22.1)}$ = 19.022, $P < 0.001$), but no difference between trials 1 to 3, or any interaction was observed ($P > 0.05$). Differences in HR ($t_{(38)}$ = -7.969, $P < 0.008$) were only noted between the first 200 m (162 ± 13 b·min^{-1}) and 400 m (187 ± 14 b·min^{-1}), across all three trials. No differences (P > 0.008) were observed between 400 – 600 m, and 600 – 800 m, across three trials. Identical statistical findings were noted for relative HR (%HRmax), with a lower average relative HR observed for the first 200 m (77.9 ± 5.6 %) than 400 m (90.3 ± 7.1 %), across the 3 trials ($t_{(38)}$ = -8.191, P < 0.008; Figure 8.5). Similarly, no differences (P > 0.008) were noted for relative HR achieved during 400 – 600 m, or 600 – 800 m, across three trials.

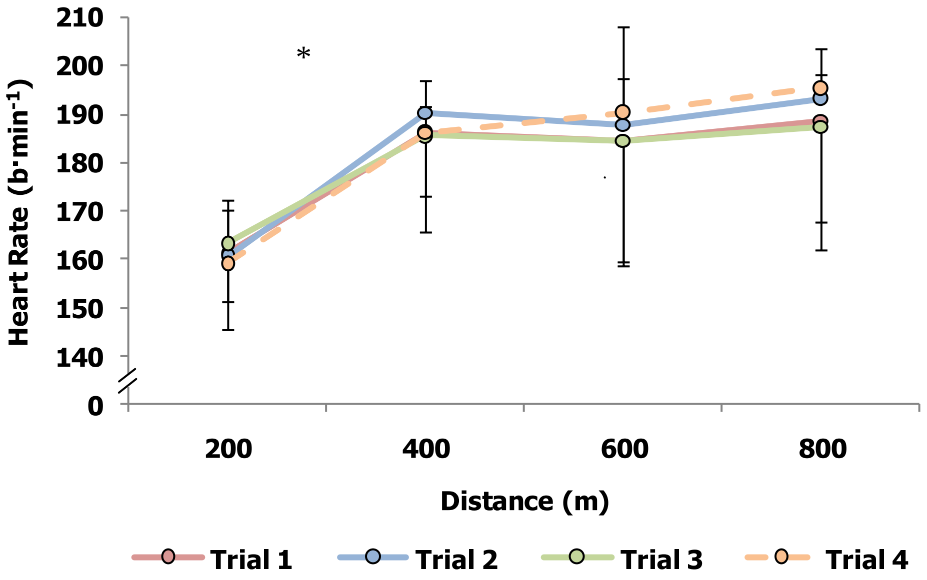

Figure 8.5. Average heart rate (b·min^{-1}) during each 200 m distance, across all field trials (1 to 4). Values are mean ± SD.

* Significant difference (P < 0.008) in average heart rate during the first 200 m distance and 400 m, for all trials (1 to 4).

8.4.4 Ratings of Perceived Exertion over 800 m, across three trials:

Significant increases in RPE were observed across each 200 m mark ($F_{(1.5, 17.9)}$ = 90.674, P < 0.05), yet no difference in the RPE across trials 1 to 3, or any interaction was observed (P > 0.05; Figure 8.6). Post-hoc analyses revealed that the RPE rose between 200 m (2.2 ± 0.9) and 400 m (4.0 ± 1.5; $t_{(38)}$ = -12.851), 400 – 600 m (5.4 ±

1.8; $t_{(38)}$ = -9.269), and 600 – 800 m (6.5 ± 2.0; $t_{(38)}$ = -9.626; all $P < 0.001$), across all three trials.

8.4.5 Physical, physiological and perceptual differences across trials 3 and 4:

The total time to complete trial 3 (242.4 ± 51.5-s) and the competition trial (trial 4; 260.5 ± 54.2-s) was approaching significance ($t_{(12)}$ = -2.033, P = 0.06; Figure 8.3). However, due to the large variation in completion times between these two trials (~ 18-s), it was deemed necessary to conduct post-hoc tests to identify whether this was a result of gender differences. Thus, paired *t* tests separated for gender revealed that there was a significant difference between trial 3 (239.0 ± 47.5-s) and the competition trial (250.0 ± 48.5-s) for boys ($t_{(7)}$ = -3.129; $P < 0.05$), but not for girls (247.8 ± 62.8-s & 277.2 ± 64.1-s, for trials 3 & 4, respectively; $P > 0.05$).

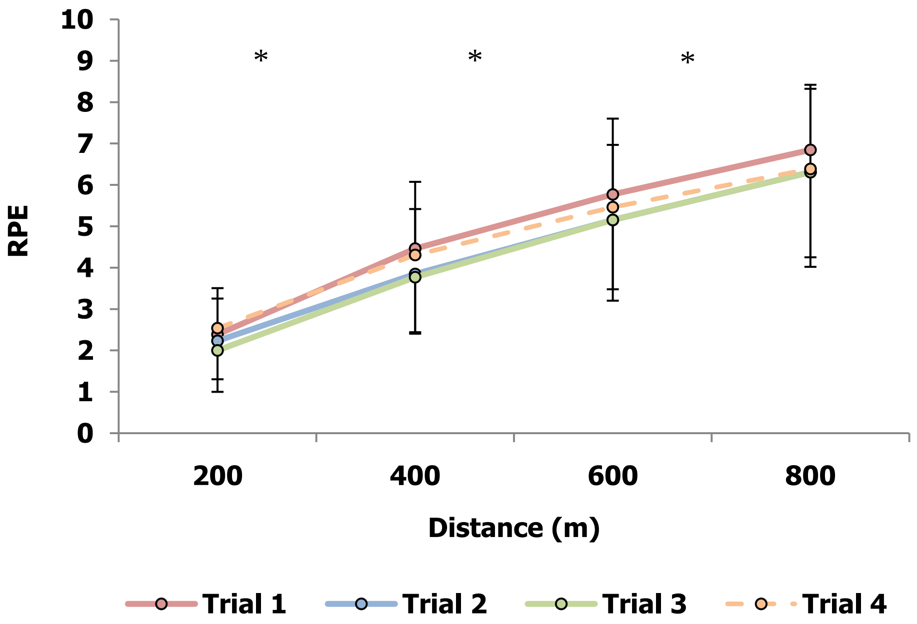

Figure 8.6. Average ratings of perceived exertion (RPE; E-P scale) reported for each 200 m distance, across all field trials (1 to 4). Values are mean ± SD.

* Significant difference ($P < 0.008$) in RPE reported during the first 200 m distance and 400 m; 400 m and 600 m; 600 m and 800 m, for all trials (1 to 4).

There was a significant difference in split times across each 200 m mark ($t_{(25)}$ = -7.657, $P < 0.001$) and across trials ($t_{(51)}$ = -2.672, $P < 0.01$). Analyses revealed that the split time for the first 200 m was significantly faster (55.0 ± 12.7-s) than the subsequent 200 m (400 m; 67.3 ± 14.2-s), and that the average split times for trial 3 (60.6 ± 13.6-s) were significantly faster than during the competition trial (63.3 ± 14.2-s; Figure 8.4).

Average HR was significantly ($t_{(25)}$ = -10.422, $P < 0.001$) lower in the first 200 m (161 ± 12 b·min^{-1}) than 400 m (186 ± 9 b·min^{-1}), but not significantly different thereafter. Moreover, there was no difference in average HR across trials three (180 ± 22 b·min^{-1}) and four (183 ± 16 b·min^{-1}; $P > 0.05$). Identical findings were observed for relative HR across trial 3 and the competition trial (trial 4; $t_{(25)}$ = -10.370, $P < 0.001$; Figure 8.5). The RPE significantly increased ($P < 0.001$) across each 200 m mark, from 200 m (2.3 ± 1.0) to 400 m (4.0 ± 1.2; $t_{(25)}$ = -13.844), 400 – 600 m (5.3 ± 1.7; $t_{(25)}$ = -5.801) and 600 – 800 m (6.3 ± 2.1; $t_{(25)}$ = -6.845), and this finding did not differ between trial 3 and the competition trial ($P > 0.05$; Figure 8.6).

8.4.6 Comparison of RPE responses across conditions (laboratory GXT cf. field-based exercise):

The average relative HR, and corresponding RPE for all participants were 77.9 %, 90.3 %, 89.5 % and 91.5 %HRmax, and 2.2, 4.0, 5.4, and 6.5 (according to the E-P scale) for 200 m, 400 m, 600 m and 800 m, respectively, across field trials 1 to 3. A significant main effect was observed for RPE across each 200 m mark ($F_{(1.6,\ 18.6)}$ = 174.336, $P < 0.001$). During the GXT, the average RPE provided at relative HR values of 77.9 % and 90.3 % (3.7 & 5.5, respectively) were statistically higher ($t_{(12)}$ = -5.457 & $t_{(12)}$ = -3.765, respectively, $P < 0.013$) than during the field trials. However, no difference was noted between the RPE reported at 89.5 % and 91.5 %HRmax during the

GXT (5.4 & 5.7, respectively) and the RPE reported at an equivalent physiological cost during the field trials ($P > 0.013$).

8.5 Discussion:

This study is the first of its kind to assess whether children aged 9 – 11 years employ pacing strategies during an 800 m running event, and whether the presence of other competitors has any influence on the chosen pacing strategy. The findings of this study indicate that children pace themselves during an 800 m run, and that this improves with trial familiarisation, to ensure that the task is completed successfully, in the fastest possible time. This was particularly evident in the total time taken to complete trials 1 to 3, wherein trial 1 was statistically slower than both trial 2 (~ 6.5-s) and trial 3 (~ 7.7-s). This represents a 2.6 – 3.1 % improvement in performance over the course of the trials. The learning effect noted in the present study with children is similar to that demonstrated with adults (Buckley et al., 2000; Eston & Williams, 1988; Eston et al., 2005, 2006, 2008). Furthermore, this study utilised a closed-loop exercise task (participants had knowledge of the end-point and distance to be covered), which replicates that typically employed by athletes during competition (Joseph et al., 2008). Schabort, Hopkins, and Hawley (1997) and Laursen, Francis, Abbiss, Newton, and Nosaka (2007) have shown that closed-loop exercise is more reproducible than open-loop exercise.

8.5.1 The 'optimal' pacing strategy:

Several scientific studies have been conducted to assess the 'optimal' pacing strategy for differing sporting situations, yet these studies remain relatively inconclusive (St Clair Gibson et al., 2006). Research into effective pacing strategies has been confounded by a number of external factors, including course geography, race duration and environmental conditions (Abbiss & Laursen, 2008). As such a number of research studies have been conducted in controlled (Atkinson & Brunskill, 2000; Foster et al., 2004; Mattern et al., 2001; Paterson & Marino, 2004) or simulated (Atkinson & Brunskill, 2000; Liedl, Swain, & Branch, 1999) environmental conditions. Moreover, research on pacing strategies is dominated by studies of cycling or running events of less than 2-mins duration, whereas, studies involving distance running are scarce (Abbiss & Laursen, 2008; Townshend, Worringham, & Stewart, 2010). It has been suggested, however, that during longer-distance events (>110-s), athletes will often employ a 'variable' pacing strategy[1] (Abbiss & Laursen, 2008; Liedl et al., 1999; Tucker, Marle, Lambert, & Noakes, 2006). Yet for shorter events (<110-s), the optimal pacing strategy has been proposed as 'all-out'[2] (Bishop et al., 2002; Foster et al., 1993; Keller, 1974; Townshend et al., 2010; Tucker et al., 2006; van Ingen Schenau, de Koning, & de Groot, 1992). Although Abbiss and Laursen (2008) suggest that an 800 m race may be considered a 'middle-distance' event with adults, for children, such as those in the current study, this distance may be considered an endurance- or prolonged event. In this regard, it is proposed that the participants in this study employed a 'variable' pacing strategy, similar to that observed for adults for an equivalent duration (Abbiss & Laursen, 2008; Foster et al., 2004; Rauch et al., 2005; Tucker et al., 2006), and as demonstrated in the average split time data across trials 1 to 3 (Figure 8.4). The average split time for the first 200 m was statistically faster than the succeeding 200 m distance (400 m), suggesting that the children employed a 'sprint start' during each trial. A comparable finding has been demonstrated previously with adults (Joseph et al., 2008; Rauch et al., 2005). In addition, the average split time for the final 200 m distance (800 m) was statistically faster than the prior 200 m (600 m), which highlights the

[1] A 'variable' pacing strategy is often characterised by a fast start, followed by a decline in pace during the middle portion of the event and an increase in speed near the end.
[2] An 'all out' pacing strategy comprises a maximal start and then a progressive decline in speed throughout the event.

occurrence of an ‘end-spurt’. An end-spurt is frequently noted in performance literature with adults, and has been evidenced in sporting situations of varying intensity and duration, or environmental conditions (Albertus et al., 2005; Joseph et al., 2008; Kay et al., 2001; Tucker, Rauch, Harlet, & Noakes, 2004; Tucker et al., 2007; Rauch et al., 2005; Tatterson, Hahn, Martin, & Febbraio, 2000). Indeed, this finding may suggest that the participants in the current study actively increased or decreased their power output to make the rate of accumulation of fatigue appropriate for each segment of the exercise trial (Joseph et al., 2008).

Nevertheless, the correct interpretation of the adopted pacing strategy by the children in this study may be confounded by the equivocal research findings concerning what is the ‘optimal’ strategy, most notably a recent publication by Tucker and Dugas (2008). The authors noted that out of the 26 races wherein a world record for the men’s 800 m has been set, 24 of these have demonstrated that the winning athlete ran the first lap (400 m) significantly faster than the second lap. It is noteworthy however that a ‘significant’ variation in average lap time only amounts to a 2-s performance difference between the first- and second lap for these athletes, thus suggesting that an ‘even pace’ is in fact commensurate with an optimal performance (Abbiss & Laursen, 2008; de Koning et al., 1999; Thompson, MacLaren, Lees, & Atkinson, 2003, 2004; Tucker & Dugas, 2008). For the children in this study, average split times for the first 400 m were also quicker (118.4-s) than the succeeding 400 m (127-s), across three trials. Although the performance difference between laps is expectedly much larger for the children in this study compared to those reported by Tucker and Dugas (8.6-s cf. 2-s, respectively), it demonstrates that the untrained children in this study may employ a similar ‘patterning’ in their pace response to these elite 800 m athletes. Nevertheless, as athletes generally learn optimal pacing strategies during training (Foster, 1994), we can infer that the pacing strategy adopted by these children during the third trial (whether ‘variable’ or more ‘even’-paced) has been modified accordingly due to an increase in exercise experience and familiarisation to the exercise task. As the findings from the current study appear to present characteristics of both a ‘variable’ and ‘even’ pacing strategy, further research is necessary to elucidate which strategy is most frequently employed-, or which is ‘optimal’, with young children. In this regard, future research is recommended to consider the influence of age- and cognitive developmental level of the children, as well as the distance, training status and exercise mode when assessing pacing strategies employed during exercise.

8.5.2 Influence of competition:

Although scientific research has assessed the various pacing strategies adopted during differing athletic events in relation to simulated competition, no research has assessed the specific influence of competitors on the chosen pace response. Statistically, no differences were noted in completion times between the third individual trial (trial 3) and the competitive trial (trial 4), despite the average time taken to complete trial 4 being ~ 18-s slower than trial 3. Indeed, this equates to an average decrement in performance of ~ 6.9 %. Although this difference is proportionally larger than that observed between trials 1 and 3, it is likely that the greater variability (SD) in completion times during the competitive trial may have weakened the statistical significance of this finding. Nevertheless, this decrease in performance is evident in the analyses of the split times across trials, which were faster during trial 3 than during the competitive trial (60.6-s cf. 63.3-s, respectively). Furthermore, the pacing strategy employed in the competitive trial was more irregular in appearance than during trial 3 (Figure 8.4). This is an interesting finding given that there were no apparent differences in the participants’ heart rates or RPE between the two conditions. Accordingly, it is postulated that internal (i.e. motivation, confidence, or perceived ability) and/or external (weather, time, opponent ability) psychological factors associated with the athletic competition must have contributed in some way to the observed differences in performance across these trials (Cooke, Kavussanu, McIntyre, & Ring, 2010; Viru et al., 2010).

Although statistically no difference was noted in the average completion time between trial 3 and the competitive trial, it was thought prudent to further investigate whether the larger variability may be attributed to gender differences. As expected, additional analyses highlighted that the average time to complete trial 4 was statistically slower than trial 3 for boys (~ 11-s). For the girls of this study however, despite the average time to complete the competitive trial being ~ 30-s slower than trial 3 (SD > 1-min), no statistical difference was observed. This is likely a consequence of the smaller number of girls (n = 5) having a greater variance in fitness status. As such, future research may be warranted to assess each of these potential influencing factors (internal and external psychological aspects; gender differences; level of fitness) within a competitive situation in order to determine their affect on overall performance and the pacing strategies employed.

8.5.3 Physiological and perceptual responses, across trials:

The average heart rate during the first 200 m was statistically lower than during 400 m across each of the four trials. This was likely a result of a delay in the heart rate response in achieving steady state during the first 200 m after the onset of exercise. Indeed, a lag-time in heart rate at the onset of exercise has been reported elsewhere with adults (Glass et al., 1992; Kang et al., 2003). Nevertheless, heart rate remained relatively consistent during the succeeding stages of each exercise trial (1 to 4) across distance, regardless of whether any changes in power output occurred as a result of the adopted pacing strategy. A similar finding was noted for RPE, in that linear increases were observed from the onset- to termination of exercise during each of the four trials. This suggests that heart rate and RPE do not merely track changes in power output (Albertus et al., 2005; Rauch et al., 2005; Tucker et al., 2004, 2007) , and that RPE is related to central neural processes involved in the maintenance of homeostasis (Tucker et al., 2004). Indeed, the aforementioned authors postulate that it would be incomprehensible for the RPE to be simultaneously reduced with power output (i.e. during the middle-portion of the 800 m event; Figure 8.4), as the natural response of the athlete would be to override this conscious effect and increase power output, thus increasing the probability of developing homeostatic failure. As such, central processes involved in exercise regulation may increase the conscious perception of exertion throughout an exercise bout to discourage any conscious overriding of this subconscious control (Tucker et al., 2004). Moreover, it has recently been proposed that the RPE may possess scalar-time properties, in that it rises as a function of the amount of work done or of how much of the exercise bout remains (Crewe et al., 2008; Eston et al., 2007; Faulkner et al., 2008; Joseph et al., 2008; Noakes, 2004). In this regard, RPE will achieve maximum levels at completion of an exercise bout, be it at the end of a self-paced time-trial performance (Albertus et al., 2005; Garcin, Wolff, & Bejma, 2003; Joseph et al., 2008; Tucker et al., 2004) or as a result of volitional fatigue (Eston et al., 2005, 2006, 2007, 2008; Garcin & Billat, 2001; Garcin et al., 1998, 1999, 2003; Horstman et al., 1979; Morgan & Borg, 1976; Noakes, 2004). Hence, the RPE is frequently advocated as a sensitive predictor of time to exhaustion (Eston et al., 2005, 2006, 2007, 2008; Faulkner et al., 2008; Garcin & Billat, 2001; Horstman et al., 1979; Morgan & Borg, 1976). Interestingly, in this study, although the RPE was shown to rise linearly over time (exercise duration), theoretical maximal RPE (in accordance with the E-P scale) was not achieved during any of the exercise tests (field trials or GXT).

8.5.4 Comparison of the ratings of perceived exertion between a laboratory GXT and field-based exercise:

During the first half of the 800 m field-event, RPE values corresponding to average relative heart rates of 77.9 and 90.3 %HRmax were statistically lower than those reported during the laboratory-based GXT, for equivalent exercise intensities. This finding has been noted previously for adults (Ceci & Hassmén, 1991; Glass et al., 1991; van den Berg & Ceci, 1986). Indeed, Ceci and Hassmén (1991) suggest that the RPE reported during field-based exercise elicits a perceived exertion response which is ~ 2 RPE units lower (Borg 6-20 scale) than a laboratory test, for a comparable intensity. It is postulated that several factors pertaining to the environmental conditions, such as wind resistance, temperature and humidity as well as other visual input and a familiarity to the exercise setting, may influence the perception of effort during field-based exercise (Ceci & Hassmén, 1991; Pennebaker & Lightner, 1980; van den Berg & Ceci, 1986). Moreover, the RPE have been correlated with numerous psychometric parameters (i.e. anxiety; depression; neuroticism; dissociation strategies) in a complex manner (Morgan, 1994; Pandolf, 1983). In a study comparing running performance and perceived exertion responses for a similar distance on either a cross-country course or an athletics track, Pennebaker and Lightner (1980) demonstrated that athletes modulate their pace according to their perception of fatigue. Interestingly though, they observed that during the cross country run – an activity requiring a great deal of external focus – participants ran faster for a similar perception of exertion than during the track run - an activity requiring very little external attentional focus. The authors asserted that factors which promoted attention to the external environment reduced the awareness of internal sensations of fatigue, and thus enhanced performance without increasing the perception of exertion. Consequently, it may be speculated that the familiarity to the external environment where the field-based exercise tests were conducted (School athletics track) may have reduced participants' anxiety levels, and / or shifted attentional focus in comparison to the laboratory test, resulting in a lower RPE. However, as these aforementioned parameters were not measured in the current study, no definitive conclusions can be made with regards to the environmental influence on the perceptual response. Furthermore, as no difference was noted between the RPE during the second half of the 800 m event and the equivalent intensities during the GXT, it is evident that further research in this area is necessary.

8.6 Conclusion:

It is evident that young, untrained boys and girls can appropriately regulate their power output (pacing strategy) during an 800 m running event on an outdoor athletics track. Furthermore, performance may be significantly enhanced by small modifications to the adopted pacing strategy, which are likely to have been learned as a result of greater exercise experience and familiarisation to the exercise task. Characteristics of both 'variable' and 'even' pacing strategies were evidenced in this study. As such, further research is necessary to elucidate the 'optimal' pacing strategy for differing sporting events in young children. Furthermore, an increased level of competition had extreme and detrimental effects on the pacing strategy adopted and the overall performance during the 800 m event with the children in this study. Therefore, future research should endeavour to identify the factors (intrinsic / extrinsic psychological aspects; gender) that may contribute to the decline in performance.

Chapter 9

Discussion

9.1 Main findings of the thesis:

The research studies in this thesis have revealed several pertinent findings in relation to the efficacy of the ratings of perceived exertion (RPE) with adults and children. Overall, it is notable that the ratings of perceived exertion have proved to be a valid and appropriate means to monitor exercise intensity and level of exertion. This has been demonstrated with both healthy, men and women of low-fitness and young children, aged 7 – 11 years, during both laboratory- and field-based exercise tasks. There were three main aims to this thesis; each addressing more specific research questions concerning the applicability of the ratings of perceived exertion with adults and children alike. Of particular importance was i) the accuracy of the ratings of perceived exertion to predict maximal oxygen uptake in a low-fit population, ii) the specific nature-, and physiological mediators of perceived exertion in young children, iii) the ability of young children to utilise pacing strategies during field-based exercise.

9.1.1 The accuracy of the ratings of perceived exertion in predicting maximal oxygen uptake from step-incremental or ramp-incremental exercise protocols:

The premise of both studies 1 and 2 was borne out of the practical concerns of conducting exhaustive stress tests with non-athletic or patients groups (Noble, 1982; Noonan & Dean 2000; Wilmore et al., 1986). If proven accurate, predicting maximal functional capacity using individual submaximal $\dot{V}O_2$ responses, as opposed to a frequently employed sample-based regression equation (that may contain inherent error), would be of great value. The findings of studies 1 and 2 suggest that the overall ratings of perceived exertion reported prior to- and including an RPE 13 provide estimates of $\dot{V}O_2max$ that are similar to measured values in low-fit men and women ($P > 0.05$). This has been shown during both estimation and perceptually-regulated graded exercise tests (GXT), regardless of whether a step-incremental- or ramp-incremental protocol is utilised. This is an encouraging finding when considering that the vast majority of research in this area has assessed the utility of such procedures with healthy, active individuals, often using repeated trials from a higher perceptual range (Eston et al., 2005, 2006; Faulkner & Eston, 2007; Faulkner et al., 2007; Morris et al., 2009). In this regard, the reliability in predictions of $\dot{V}O_2max$ when using the RPE has been shown to improve with familiarisation (Buckley et al., 2000; Eston & Williams, 1988; Eston et al., 2005, 2006, 2008; Faulkner et al., 2007). However, in studies 1 and 2 of this thesis, accurate estimates of maximal functional capacity were obtained from a single exercise session from a lower perceptual range (RPE 9-13). Faulkner et al. (2007) have reported accurate predictions of $\dot{V}O_2max$ from exercise intensities prior to- and including an RPE 13 from the first of three perceptually-regulated GXTs, with active and sedentary individuals.

With regards to the potential utility of the RPE, exercise protocols that utilise low to moderate intensities, such as those employed in studies 1 and 2, may be considered more appropriate for monitoring and prescribing exercise to sedentary or some clinical groups who are likely to be more negatively affected by the demands of high-intensity exercise (Hardy & Rejeski, 1989; Parfitt & Eston, 1995; Parfitt, Markland, & Holmes, 1994; Parfitt et al., 1996). It is interesting that participants were performing at ~ 57 – 69 % of their $\dot{V}O_2max$ when exercising at an RPE 13, regardless of protocol, in accordance with previous research (Dunbar et al., 1994; Faulkner et al., 2007). Although it was postulated that predictions of $\dot{V}O_2max$ from an individual's gaseous exchange threshold (GET) may reduce the intensity and duration of a stress test, the findings of study 2 suggest that predictions from the GET are relatively inaccurate in a low-fit population. Perhaps a more appropriate measure may in fact be the oxygen consumption reserve ($\dot{V}O_2R$) as detailed by the ACSM (2010), as the use of $\dot{V}O_2R$ in exercise prescription provides more accurate target workloads, especially for individuals of low-fitness (Swain, 2000). In this regard, the participants in study 2 were exercising at 60 %$\dot{V}O_2R$, in accordance with the recommendations of the ACSM (2010) for exercise prescription. The $\dot{V}O_2R$ could not be retrospectively calculated for the participants of study 1 however as no period of baseline measurement of $\dot{V}O_2$ was conducted prior to the GXT.

A single exercise test that facilitates accurate estimates of $\dot{V}O_2max$ may also be of particular benefit when considering the clinical application of the RPE. Apart from reducing the necessary time and numerous costs involved in stress testing, it may reduce the prolonged discomfort and clinical risk, as well as the motivational requirements for the individual concerned. In this regard, although a direct comparison was not made between exercise protocols (step-incremental cf. ramp-incremental), it may be assumed that a ramp-incremental GXT may be more appropriate in the prediction of $\dot{V}O_2max$. Indeed, the time taken to achieve an RPE 13 when estimated by the low-fit women (6 min cf. 6 min 32-s, for step-incremental & ramp-incremental protocols, respectively) was similar between studies 1 and 2. But perhaps more importantly, the estimates of $\dot{V}O_2max$ were more accurate from the ramp-incremental protocol (study 2), as demonstrated by the improved measures of agreement in predictions (LoA; ICC). It is postulated that the continual rate of change in work rate during study 2 may have amounted to a more frequent appraisal of exertional symptoms, and thus facilitated a more accurate rating than that provided during study 1 for a 3-min step-incremental GXT. As a consequence, more accurate estimates of $\dot{V}O_2max$ may be obtained from a ramp-incremental protocol, although further research may be necessary to explore this inference.

9.1.2 Comparison of the accuracy in predicting maximal oxygen uptake from the ratings of perceived exertion and heart rate:

Often, the basic aim of employing submaximal exercise procedures is to determine an individual's heart rate response to one or more submaximal work rates and use these results to predict $\dot{V}O_2max$ (ACSM, 2010). One such common method is that of the Åstrand-Ryhming nomogram (Åstrand & Ryhming, 1954). As such, a secondary purpose of studies 1 and 2 was to determine whether the ratings of perceived exertion may be as good as- if not better than heart rate at determining an individual's $\dot{V}O_2max$. The findings of these studies suggest that the ratings of perceived exertion may provide more accurate estimates of maximal oxygen uptake than submaximal heart rate, in low-fit men and women. Although predictions were similar to measured values from methods involving either the ratings of perceived exertion or heart rate across both studies, the measures of consistency (LoA; ICC) are perhaps more pertinent. In best case scenario, predictions of $\dot{V}O_2max$ involving the ratings of perceived exertion demonstrated narrower limits of agreement (LoA study 1: 1.0 ± 8.5; study 2: -0.41 ± 5.64) and higher intraclass correlation coefficients (ICC study 1: R^2 = 0.77; study 2: R^2 = 0.96) than the methods involving heart rate (LoA study 1: -0.4 ± 13.7; study 2: -0.1 ± 9.1; ICC study 1: R^2 = 0.68; study 2: R^2 = 0.85), during both studies.

In recognition that many exercise practitioners may not have suitable access to appropriate equipment for the measurement of oxygen consumption during exercise, the information amassed from studies 1 and 2 led to the development of a regression equation. This regression equation incorporated aspects of the ratings of perceived exertion, in relation to work rate, and heart rate in order to predict the $\dot{V}O_2max$ of low-fit women. The findings of study 2 demonstrated that the combination of both measures (RPE and predicted heart rate maximum) resulted in accurate estimates of maximal functional capacity in healthy women of low-fitness. Previous research has shown the

$\dot{V}O_2$: HR relationship during exercise to be comparable for both men and women (Franklin, Hodgson, & Buskirk, 1980), and thus a common regression equation may be valuable for purposes of exercise prescription (Johnson & Prins, 1991). However, further research may be warranted with a larger population of both men and women in order to assess the true validity and reliability of this procedure within a practical setting.

9.1.3 Validation of a ratings of perceived exertion scale, and the evaluation of the nature of perceptual responses during cycling and running exercise, in young children:

The rationale for studies 3 and 4 was informed by the recently devised Eston-Parfitt (E-P) paediatric ratings of perceived exertion scale. The E-P scale design illustrates a curvilinear relationship between the ratings of perceived exertion and work rate, as opposed to the commonly observed linear ratings scales. Although curvilinear relationships between the ratings of perceived exertion and parameters such as work rate or heart rate have been observed previously (Barkley & Roemmich, 2008; Lamb, 1995; Roemmich et al., 2006), no studies have sought to investigate the precise nature of the perceptual response to increasing work, in young children. The findings of studies 3 and 4 suggest that the E-P scale is a valid means of assessing a child's level of exertion across a wide range of exercise intensities, during cycle ergometry and treadmill exercise. Yet, as both studies employed a discontinuous, incremental exercise protocol, future research should investigate the utility of the E-P scale during continuous exercise. These studies also revealed that children aged 7 – 8 years may demonstrate both linear and curvilinear increases in their perception of exertion with work rate, during cycle ergometry and treadmill exercise. The importance of this finding is primarily for the exercise practitioner / physical education instructor, to ensure that they acknowledge this factor when assessing perceived exertion responses of young children in order to monitor or prescribe exercise appropriately.

9.1.4 Physiological mediators of the perceptual response during cycling and running, in young children:

It was the postulation that ventilatory responses may be the strongest influencing variable (Eston & Parfitt, 2007) that led to the subsequent investigation into the potential mediators of the perceptual response to exercise in young children. Of particular interest were cardio-respiratory variables, such as oxygen uptake, heart rate and ventilation, which have been tenaciously linked for a number of years to the ratings of perceived exertion in adults. The findings of studies 3 and 4 however appear somewhat inconclusive, in as much a no one clear variable mediates the perceptual response across exercise modes, and is dependent on upon the ratings method employed. In this regard, when using the E-P scale, ventilation appears to have the greatest single influence on the perception of exertion during cycle ergometry exercise yet during treadmill running, heart rate may be the strongest mediator (95 % & 97 % of the variance in RPE which is accounted for by physiological responses, respectively). Conversely, if using the novel marble task (as employed in both studies 3 & 4), ventilation emerges as the greatest influence on the ratings of perceived exertion during both cycle ergometry and treadmill exercise (100 % & 93 % of the variance in RPE which is accounted for by physiological responses, respectively). From these findings we can infer that oxygen uptake does not play a predominant role in the formation of a subjective perception of exertion in young children, during the exercise modes investigated. However, ventilation and heart rate may both be strong physiological mediators, in keeping with previous research in adults (Edwards et al., 1972; Hampson et al., 2001; Pandolf, 1983; Robertson, 1982; Skinner et al., 1973; Winsmann &

Goldman, 1976). Further research is necessary in this area to elucidate whether the mode of exercise affects the strength in which one physiological variable mediates the perceptual response over another.

9.1.5 The employment of pacing strategies by children during track running:

It is evident in the findings of study 6 that children aged 9 – 11 years employ pacing strategies during a prolonged bout of exercise, similar to adults, to ensure successful task completion in the fastest possible time. Moreover, that the degree of accuracy of the chosen pacing strategy may improve with prior learning and training, which is most likely attributed to greater exercise experience of task duration, course elevation and terrain, as well as intrinsic factors such as level of motivation and fatigue (Ansley et al., 2004a, 2004b; Bishop et al., 2002; Ceci & Hassmén, 1991; de Koning et al., 1999; Foster et al., 1993, 1994; Morgan, 1994; Rauch et al., 2005; St Clair Gibson et al., 2006). This was observed during study 6 though improvements in completion times across trials 1 to 3 ($P < 0.017$). Yet, what is interesting in this finding is how similar the performance times are between trials 1 and 3 (7.7-s) when considering that trial 1 was the first ever attempt at completing a continuous 800 m run for these children. This suggests that untrained, young children may possess a unique, inherent ability to appropriately regulate their energy expenditure across a given distance, despite no prior experience at completing such an event. Further research is necessary however to elucidate the ‘optimal’ pacing strategy for differing sporting events in young children. Interestingly, the distinct level of competition during trial four had quite a sizeable and detrimental effect on the pacing strategy adopted and subsequent performance times recorded, for the participants in this study. It is plausible that the girls were particularly influenced by the nature of competition, which may have led to increased levels of anxiety and/or a decreased motivation to perform the task to the best of their ability.

Future research should consider the potential effects of competition on performance, with specific regards to the various contributing internal- and external psychological factors, across genders. It was also interesting to note that on occasion, the ratings of perceived exertion were statistically lower during the field-trials than during the laboratory based GXT for a comparative physiological cost. This has been documented previously (Ceci & Hassmén, 1991; Glass et al., 1991; van den Berg & Ceci, 1986). However, it is imperative that we have an assurance of the accuracy of the ratings of perceived exertion across differing exercise situations, particularly if the RPE are to be utilised for the accurate prescription of exercise outside of a laboratory setting. Thus, further comparative research between the laboratory and field-based exercise programmes is recommended.

9.1.6 Thesis Summary:

This thesis has demonstrated the utility of the ratings of perceived exertion in providing accurate estimates of maximal functional capacity in men and women of low fitness, during differing exercise protocols (studies 1 & 2). Importantly, this has been shown from a low-moderate exercise intensity and from a single exercise test, which may be deemed more appropriate for low-fit individuals. This procedure offers a convenient, low cost approach to predicting $\dot{V}O_2max$ in a low-fit population. Furthermore, the RPE is advocated as a valuable tool that can be easily employed as an adjunct to heart rate to provide supplementary clinical information that is superior to using heart rate alone. Study 5 of this thesis was the first attempt at employing the novel application of the ratings of perceived exertion for predicting $\dot{V}O_2max$ with young children. On the basis of the findings of this thesis, however, the employment of this procedure is not recommended with young children as potential inaccuracies in predicting $\dot{V}O_2max$ may subsequently lead to a lack in future exercise adherence.

Within this thesis, the newly-devised curvilinear E-P scale was validated as an appropriate means of assessing perceived exertion in young children (aged 7-11 years), across differing modes of exercise (studies 3, 4 & 6). Notably, this research revealed that young children may perceive exercise intensity in either a linear or curvilinear fashion in relation to increasing work; a concept that has not been considered in prior scientific literature. Moreover, this thesis provided evidence that ventilatory and heart rate responses may be predominant physiological mediators of perceived exertion during cycle ergometry and treadmill exercise, with children of this age. Finally, study 6 of this thesis was the first of its kind to assess whether children employ pacing strategies during an 800 m running event on an outdoor athletics track. This research demonstrated that young, untrained children (aged 9 – 11 years) can pace themselves during a running event with no prior familiarisation to the exercise task. Significantly, it was demonstrated that exercise performance may be enhanced with repeated trials, yet a competitive situation may in fact be detrimental to a recently learned pacing strategy, and thus overall exercise performance. This is a novel area of research that warrants future attention.

9.2 Limitations of the research studies:

9.2.1 Limitations of the prediction of maximal oxygen uptake using the ratings of perceived exertion:

Despite the evident ‘accuracy’ in predicting $\dot{V}O_2$max using the ratings of perceived exertion, in some instances, the measures of consistency, more specifically the limits of agreement (LoA) analyses, revealed large discrepancies between measured- and predicted $\dot{V}O_2$max. This was particularly evident during study 2 when extrapolating submaximal $\dot{V}O_2$ and RPE responses from the gaseous exchange threshold (GET). In this instance, LoA analysis revealed that measured $\dot{V}O_2$max may be overestimated by as much as 14 ml·kg^{-1}·min^{-1} or underestimated by 19 ml·kg^{-1}·min^{-1}, which equates to a margin of error in predictions of $\dot{V}O_2max$ of 46 – 61 %. As such, predicting from the GET is not recommended at this stage. When using the ratings of perceived exertion prior to- and including an RPE 13, the LoA appear wider when employing a step-incremental protocol (study 1) as opposed to a ramp-incremental protocol (study 2), with a low-fit population. In this regard, the LoA from Study 1 are comparative to those reported previously for both high- and low-fit men and women, from a higher perceptual range (9-15, 9-17; Eston et al., 2008; Faulkner & Eston, 2007; Faulkner et al., 2007; Morris et al., 2009). The LoA from study 2 however are more comparable to those reported previously by Eston et al. (2005, 2006) from a higher perceptual range (9-17), with healthy, active men and women. As such, the reliability of $\dot{V}O_2max$ predictions when using the ratings of perceived exertion may be related more to the protocol employed rather than the population, as previously implied by Eston et al. (2008). Further research is necessary to identify the most appropriate protocol for estimating $\dot{V}O_2max$ from the ratings of perceived exertion provided during a low-moderate intensity exercise test, with healthy, low-fit men and women.

9.2.2 Methodological concerns:

a) Indirect comparison between differing protocols:

Several of the research questions concerning the current application of the ratings of perceived exertion to predict $\dot{V}O_2max$ were related in some way to the protocols employed in studies 1 and 2. It was perhaps an oversight to have utilised two differing protocols in these studies, as opposed to performing a direct comparison between a step-incremental and a ramp-incremental protocol during study 2. A direct comparison would have strengthened the findings with regards to the accuracy and agreement between measured- and predicted $\dot{V}O_2max$ when using the ratings of perceived exertion. As stated previously, this is a pertinent research area, particularly when considering the employment of such procedures with patient of clinical groups.

b) Protocol concerns:

Although not a critical factor, the employment of a baseline measurement when conducting the maximal GXT or perceptually-regulated protocol during study 1 would have been beneficial. Such a baseline measurement was employed during study 2, and this allowed for the calculation of the participants' oxygen consumption reserve ($\dot{V}O_2R$); recommended as an appropriate means of prescribing exercise to individuals of low-fitness (ACSM, 2010).

It is plausible that changes in field conditions (i.e. environmental temperature; sunshine cf. cloud) may have influenced the findings of study 6; particularly as such factors are proposed to influence the chosen pacing strategy (Foster et al., 1994; St Clair Gibson et al., 2006; Tucker & Noakes, 2009). Moreover, it is acknowledged that diurnal variation in maximal oxygen consumption (Hill, Cureton, Collins, & Grisham, 1988; Hill, Cureton, & Collins, 1989, Williams & Hill, 1995) and circadian variation in muscle force – which has been linked to circadian changes in performance (e.g. time or distance; Racinais, 2008) – may have also been contributing factors in overall performance, across the differing exercise trials. Although these conditions were controlled for as far as possible within the time constraints of the study, some day-to-day variation was expected.

c) Participants and sample size:

Due to recruitment issues during study 2, a women-only sample was utilised for the purpose of estimating $\dot{V}O_2max$. Although the original recruitment drive was aimed at both men and women, similar to study 1, the uptake of male volunteers was minimal.

Reasons for this are speculative; however, it is possible that the remuneration offered for participation in study 2 (a detailed health & fitness evaluation) was more appealing to women than men, in the age range concerned. It is recognised that with regards to the regression equation developed in study 2, a population of both men and women would have been beneficial. Moreover, despite the devised regression equation predicting $\dot{V}O_2max$ accurately, a larger sample size would be more effective in the development of a regression equation for use within the wider population. Sample size was a further concern during study 6 when considering the significant difference in completion times of the 800 m run for girls. Obviously a sample of girls greater than five would have been necessary if a gender comparison had been a research aim of this study. However, as this was not the case, the wide variation in completion times between these five girls resulted in a lack of statistical significance between trials, where perhaps a statistical difference should have been evident. Moreover, although a minimal difference was observed in the average $\dot{V}O_2max$ recorded for all participants during the initial GXT (SD: 8.7 $ml \cdot kg^{-1} \cdot min^{-1}$), perhaps a more rigorous selection procedure is warranted so that children are matched for their level of fitness. These factors should be taken into consideration if future research continues to investigate pacing strategies in young children.

9.3 Future research:

9.3.1 Clinical application of the ratings of perceived exertion:

In conjunction with previous research (Eston et al., 2005, 2006, 2008; Faulkner & Eston, 2007; Faulkner et al., 2007; Morris et al., 2009), the evidence provided from the studies in this thesis suggest that the ratings of perceived exertion provide generally acceptable estimates of maximal functional capacity in healthy individuals of both high- and low-fitness. Future research is necessary however to evaluate the applicability of these procedures within a hospital or rehabilitation setting. More specifically, with regards to certain patient groups, who are known to elicit a differing level of tolerance and general response to exercise than their healthy, active counterparts (Eston et al., 2005). This is a pertinent area of research, particularly when considering the numerous benefits surrounding conducting a single stress test of low-moderate intensity with populations who may be deemed of higher risk of cardiovascular complications (Eston et al., 2005; Hardy & Rejeski, 1989; Parfitt et al., 1996). Research should continue to assess methodological aspects of these procedures, in order to exact the most appropriate protocol for the employment with low-fit and criterion groups. This may include, for example, investigation into the utility of a perceptually-regulated, ramp-incremental protocol in the prediction of $\dot{V}O_2max$. Research should also be stringent in its scientific design, such as randomising protocols to improve the validity of the investigation, much like the recent study of Morris et al. (2009). Yet, in consideration of convention, and the reliance on the measurement of heart rate during exercise procedures, future research may be directed towards the development of a suitable regression equation that incorporates both heart rate and the ratings of perceived exertion, to predict $\dot{V}O_2max$. However a large sample size, incorporating both men and women would be advocated in the development of such an equation. Finally, research should explore the consistency in the ratings of perceived exertion across differing exercise situations (laboratory cf. field-based exercise), to ensure the safe prescription of exercise regardless of environmental conditions.

9.3.2 The ratings perceived exertion in young children:

Although research into the ratings of perceived with children has been prolific, particularly in recent years, there are still numerous unanswered questions and a distinct lack of congruence amongst some of the recent findings. In relation to the later point, this is particularly true when considering the age- and cognitive developmental level of children often employed in scientific studies in this area. The majority of research to date has utilised children aged 8 – 12 years of age (Groslambert & Mahon, 2006).Yet in accordance with Piaget (1999), these children may borderline between the preoperational – concrete operations stage, and the concrete operations – formal intelligence stage of cognitive development. As such differences in maturational status would clearly impact upon a child's capabilities during exercise testing procedures, it may lead us to question some of the inferences made during past research with regards to utility of the ratings of perceived exertion in this population. As such, future studies should consider using participants that are grouped according to specific age-ranges that correspond with recognised cognitive- and maturational levels. This would facilitate a more rigorous and comprehensive understanding of perceived exertion in children.

It was a finding of this research that children do not tend to report a maximal ratings of perceived exertion value, in accordance with the E-P scale, at exhaustion. This finding has been noted elsewhere with other perceptual scales (Barkley & Roemmich, 2008). This suggests that children of this age do not possess adequate experience of exercising to such high intensities, and therefore cannot utilise memory-recall anchoring techniques (as recommended with adults) sufficiently, in order to construct an appropriate exercise intensity range prior to the onset of exercise (Eston, 2009b). Alternatively, the discontinuous nature of the exercise protocol and short duration of exercise stages (1-min) may have impacted upon the perceptual responses of these children in some way. As research concerning the effect of protocol on the RPE response in children is relatively scarce, future research in this area is recommended, in addition to the influence of memory-recall or experiential anchoring techniques on a child's perceptual response, during high-intensity exercise.

A number of recent studies have shown that maximal functional capacity may be predicted with some accuracy from estimation or perceptually-regulated exercise procedures, in high- and low-fit men and women (Coquart et al., 2009b; Eston et al., 2005, 2006, 2008; Faulkner & Eston, 2007; Faulkner et al., 2007; Morris et al., 2009). Yet, as demonstrated in study 5, this does not appear to be the case in young children. The efficacy of the ratings of perceived exertion in predicting $\dot{V}O_2max$ accurately is undoubtedly affected by age, cognitive ability and duration of exercise bouts (Eston, 2009a). Consequently, future research should further explore the efficacy of these techniques with children.

9.3.3 The development of pacing strategies during exercise:

This thesis showed that young children employ pacing strategies during exercise, much like adults. However, further research in this area is limited. Future research is necessary to explore the pacing strategies adopted by children during events that differ in intensity and duration, and whether expected task duration may have any influence on the perceptual response or subsequent pacing strategy employed. Moreover, future research should assess to what extent other environmental (weather / terrain) and situational factors (experience / competition / motivation) affect these differing pacing strategies in children. As the children in this thesis were young (9 – 11 years), it would be of interest to investigate at what stage of a child's cognitive development does the ability to pace themselves become apparent. Is it an inherent ability that all children possess? Or is it a learned process?

Chapter 10
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Information Sheet
Study 1

Prediction of maximal oxygen uptake from the Åstrand-Ryhming nomogram and ratings of perceived exertion

Thank you for your interest in this project. Please take time to read this information sheet carefully before deciding whether or not to participate. Details about the study and what we would like to do will be given. If you decide to participate we thank you. If you decide not to take part, there will be no disadvantage to yourself and we thank you for considering our request.

What is the aim of the project?

This project is being undertaken as part requirement of a PhD in Sport and Health Sciences. We are particularly interested in investigating the perception of exertion of men and women of low-fitness, during cycling exercise. We aim to identify which of four specific methods can provide the most accurate prediction of your maximum exercise capability.

What type of participant is needed?

Men aged between 18 and 45 years old, and women aged between 18 and 55 years old, who are of low-fitness and have no known medical conditions.

What will participants be asked to do?

You will be asked to visit the laboratory at the School of Sport and Health Sciences (St Luke's Campus, University of Exeter) on two occasions, each separated by a 48 hour recovery period. On the first visit to the lab you will undertake basic height, weight and blood pressure measurements. The duration of each visit will vary, but none will last more than one hour. During each visit you will be asked to complete a bike test. Each test will last between 6 – 20 minutes and will range in difficulty. During one visit you will be asked to complete a maximal test to exhaustion. This involves exercising at various exercise intensities on a stationary exercise bike, and will take between 10 – 15 minutes to complete. During the other visit you will be asked to exercise at five different exercise intensities, which will be set by you. Following a 30-min recovery you will be asked to exercise at a light-moderate exercise intensity for 6 – 7 minutes. During each exercise test you will be asked to use a Ratings of Perceived Exertion (RPE) scale to reflect how hard you feel you are working whilst exercising. Furthermore, you will be asked to wear a facemask and heart rate monitor throughout each test so that we can measure your breathing and heart rate whilst you exercise.

Can participants change their mind and withdraw from the project?

You may withdraw from participation in the project at any time and without any disadvantage to yourself of any kind.

What data or information will be collected and what use will be made of it?

Results of this project may be published but any data included will in no way be linked to any specific participant.

You are most welcome to request a copy of the results of the project should you wish.

The data collected will be securely stored in such a way that only those within the research team will be able to gain access to it.

What if participants have any questions?

If you have any questions about our project, either now or in the future, please feel free to contact either:

Miss Danielle Lambrick	or	Professor Roger Eston
PhD Research Student		Head of School
(01326) 262818		(01392) 264720

This project has been reviewed and approved by the Ethics Committee of the School of Sport and Health Sciences

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Information Sheet
Study 2

Prediction of maximal oxygen uptake from submaximal ratings of perceived exertion and heart rate during a continuous exercise test: the efficacy of RPE 13

Please read this information sheet carefully before deciding whether or not to participate in the above study. The following information will tell you more about the study. If you decide not to take part, we thank you for considering our request.

Background information to the study:

Perceived exertion relates to the feelings people have while exercising. The effort involved, breathlessness and fatigue are three examples of factors that influence people's perception of exertion during exercise. Borg's 6-20 Ratings of Perceived Exertion (RPE) scale is a valuable and reliable tool that helps monitor feelings of exertion during exercise. It provides exercisers of all fitness levels with easily understood perceptual guidelines regarding exercise intensity.

What is the aim of the study?

The purpose of this study is to assess whether a 6-min submaximal exercise test can provide accurate predictions of maximal oxygen uptake ($\dot{V}O_2max$) using the RPE. Maximal oxygen uptake is a physiological marker that is widely recognised as the best measure of an individual's aerobic fitness.

What participants are needed?

Healthy, untrained men (under the age of 45) and women (under the age of 55), who are asymptomatic of illness or pre-existing injuries are required to take part in the study.

Exclusion criteria:

Men and women over the age of 45 and 55, respectively, people who are over-weight according to their Body Mass Index (BMI), and people who suffer from chest pains, heart trouble, or muscular problems which may be aggravated by exercise will be excluded from the study. We will also measure your blood pressure, total cholesterol and non-fasting blood glucose levels to ensure that it is safe for you to exercise.

What will you have to do?

You will be asked to attend the Richards Building Physiology Laboratory at the School of Sport & Health Sciences (St Luke's Campus, University of Exeter) on two occasions to perform one exercise test on each visit. There will be approximately a 48 to 72 hour recovery period between exercise tests. The exercise tests will be performed on a cycle ergometer (stationary bike). Prior to the initial exercise test your height, weight and blood pressure will be measured. Additionally, your non-fasting blood glucose and total cholesterol level will be assessed via a capillary blood sample (fingerprick blood sample). Your first exercise test will involve a graded exercise test to volitional exhaustion to establish your $\dot{V}O_2max$. This will be continuous and incremental in style, commencing at a low exercise intensity and becoming progressively harder. On your second test, you will be required to perform a submaximal exercise test. During this test you will cycle for 6-min at a low-moderate exercise intensity. You will be asked to estimate your RPE at each minute of the exercise test.

You will be required to provide informed consent to your participation in this study. Participants will be provided with detailed feedback following their assessment sessions. Feedback will incorporate information relating to their general health status (blood pressure, BMI, cholesterol, blood glucose), and their performance in the exercise test (heart rate response, maximal oxygen uptake).

What are the risks?

A trained investigator will take blood samples in accordance with universal procedures and precautions. Blood sampling is largely painless, and the volume of blood taken is very small. Some people may be affected by 'needle phobia', which may cause some distress. Light-headedness, nausea, fainting and abnormal blood pressure can be associated with intense exercise. However, we will minimise the likelihood of these experiences by accompanying your exercise test with a low-intensity warm-up and a low-intensity cool down. There is a remote risk of death associated with intense exercise; approximately 1 death in 50,000 exercise tests in coronary patients. In normal, healthy adults, this risk is lower still. All exercise tests will be conducted in a laboratory equipped with an automated external defibrillator and the investigators involved in the research study are trained in emergency life support.

Can participants change their mind and withdraw from the study?

Participants can stop taking part in the project at any time and without prejudice to themselves.

What will be done with the data?

Any data collected from this study will be coded so individual anonymity will be maintained. Data will be analysed and any results may be published. Participants are welcome to request a copy of the final results of this study. All data will be held for a period of five years following the date of collection and will be securely stored in such a way that only those in the research team will be able to gain access to it.

What if participants have any questions?

If you have any questions about our project, either now or in the future, please feel free to contact either:

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or

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Information Sheet
(Parent / Guardian)
Study 3

The perceptual response to exercise of progressively increasing intensity in children aged 7-8 years: validation of a pictorial curvilinear ratings of perceived exertion scale

Thank you for your interest in this study. Please take time to read this information sheet carefully before deciding whether or not to give your consent for your child to participate. Details about the study and what we would like to do will be given. If you decide to allow your child to participate we thank you. If you decide that you do not wish your child to participate, there will be no disadvantage to you or your child and we thank you for considering our request.

What is the aim of the project?

This project is being undertaken as part-requirement of a PhD in Sport and Health Sciences. We know that children have the ability to rate their perception of exertion when they are exercising. A number of ratings of perceived exertion (RPE) scales have been developed for use with children; however they assume that a child increases their perception of exertion in a linear fashion with increasing exercise intensity. Recent research has led to the development of a pictorial RPE scale that may be more appropriate for children.

What type of participant is needed?

Active children aged 7 – 8 years, with no known medical conditions.

What will participants be asked to do?

Each child will be asked to visit the exercise physiology laboratory at the School of Sport and Health Sciences at the University of Exeter, accompanied by a teacher, where they will complete an exercise test on a cycle ergometer (used for indoor cycling). This exercise test will involve your child cycling to volitional exhaustion, following a standardised protocol. Volitional exhaustion means that your child may stop the exercise test at any point. During this visit to the laboratory, your child will have his/her height and weight measured.

Throughout the test, your child will be asked to wear a heart rate monitor and a facemask so that heart rate and respiratory gases can be measured continuously. Through the use of a specially designed pictorial chart (E-P scale, see attached diagram), and a container of marbles, your child will also be asked to rate how hard they feel each bout of exercise is. The first method will involve pointing- or sliding a marker along the curvilinear scale to a picture/phrase/number that best describes their feelings of exertion at the time. The second method will require your child to remove a desired number of marbles from one container and place them into another container. The easier the exercise bout feels to your child, the less marbles that he/she will collect from the container. As the exercise becomes harder, more marbles will be collected from the container. It will be made clear to each participant that there are no right or wrong answers during these tasks.

Can participants change their mind and withdraw from the project?

Participants may withdraw from participation in the project at any time and without any disadvantage to the child or parent/ guardian of any kind.

What data or information will be collected and what use will be made of it?

Participants will have their height and weight measured, and physiological data will be recorded. Participants will also have their subjective RPE responses noted.

The data collected will be securely stored and anonymised in such a way that only those within the research team will be able to gain access to it.

Results of this project may be published but any data included will in no way be linked to any specific participant.

You are most welcome to request a copy of the results of the project should you wish.

What if participants/ parents/ guardians have any questions?

If you have any questions about our project, either now or in the future, please feel free to contact either:

Miss Danielle Lambrick (01326) 262818 or Professor Roger Eston (01392) 264720

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Information Sheet
(Participant)
Study 3

The perceptual response to exercise of progressively increasing intensity in children aged 7-8 years: validation of a pictorial curvilinear ratings of perceived exertion scale

Thank you for showing an interest in this study. Please read everything below before deciding if you want to take part. This information sheet will tell you a little more about the study and what we would like you to do. If you decide not to take part it will not affect your relationship with the research team or your school.

What is this project about?
This study is to find out how you feel when you exercise.

Who can take part in the study?
If you are 7 or 8 years old and are able to cycle during hard exercise you can take part in this study.

What will I have to do?
If you decide that you want to take part in this study, you will firstly be asked to visit the School of Sport and Health Sciences at the University of Exeter and take part in an exercise test. This test will involve you cycling for about 10 minutes at a comfortable speed on a piece of equipment called a cycle ergometer. This test will start off quite easy, but it will get harder and harder until you will have to stop cycling. You may get tired and out of breath in this test, but you can stop the test whenever you want to. During this visit, you will also have your height and weight measured. When you are cycling we want you to tell us how hard you think it is to cycle. To help you to decide, we will show you a picture scale and then ask you to point to a picture, a word or a number on the scale that is most like how you feel. We will also ask you to take some marbles out of one container and put them into another container. The harder the exercise feels to you, the more marbles you take out of

the container. When you are cycling, we will ask you to wear two bits of equipment that will measure how hard your body is working when you are exercising. One is a belt that you will wear around your chest which measures heart rate and the other is a facemask that will collect the air that you are breathing in and out.

When will I do it?
You can take part during school time. When you visit the School of Sport and Health Sciences, you will be brought from your school by one of your teachers. Afterwards, you will be taken back to your school by your teacher. You will be away from your school for about 1 - 2 hours if you take part in this study.

Can I stop taking part if I want to?
You can stop taking part in the project at any time if you want to, and it will not affect your relationship with the research team or your school.

What will you do with the information?
All of the information that the researchers collect will be kept on a computer and the results will be confidential to the School of Sport and Health Sciences research team.

What if I have any questions?
If you have any questions, you can ask any member of the research team at any time.

What do I do next?
If you have read and understood everything that we will ask you to do and you would like to take part, please tick the box that says 'I agree to take part in this project' and print your name on the assent form that is attached to this sheet. Also, please ask your parent/ guardian to sign the consent form that is attached to their information sheet.

Thank you,
Danielle

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Information Sheet
(Parent / Guardian)
Study 4

The perceptual response to treadmill exercise using the Eston-Parfitt Scale and marble dropping task, in children aged 7-8 years

Thank you for your interest in this study. Please take time to read this information sheet carefully before deciding whether or not to give your consent for your child to participate. Details about the study and what we would like to do will be given. If you decide to allow your child to participate we thank you. If you decide that you do not wish your child to take part, there will be no disadvantage to you or your child and we thank you for considering our request.

What is the aim of the project?

This project is being undertaken as part-requirement of a PhD in Sport and Health Sciences. We know that children have the ability to rate how hard they feel they are working when they are exercising. A number of ratings of perceived exertion (RPE) scales have been developed for use with children; however they assume that a child increases their perception of exertion in a linear fashion with increasing exercise intensity. Recent research has led to the development of a pictorial RPE scale that may be more appropriate for children. This particular scale has recently been validated with children aged 7-8 years during cycle ergometry exercise[†] however its validity is yet to be established during running.

What type of participant is needed?

Active children aged 7-8 years, with no known medical conditions.

[†]All participants for this study were Exeter Junior School pupils. Further information concerning the procedures involved and the results of this study can be obtained from posters on display around Exeter School.

What will participants be asked to do?

Each child will be asked to visit the exercise physiology laboratory in the School of Sport and Health Sciences, St Luke's campus at the University of Exeter, accompanied by a teacher, where they will complete an exercise test on a treadmill (used for indoor running). This exercise test will involve your child running to volitional exhaustion, following a standardised protocol. Volitional exhaustion means that your child may stop the exercise test at any point. During this visit to the laboratory, your child will have his/her height and weight measured.

Throughout the test, your child will be asked to wear a heart rate monitor and a facemask so that heart rate and respiratory gases can be measured continuously. Through the use of a specially designed pictorial chart (E-P Scale, see attached diagram) and a marble task, your child will also be asked to rate how hard they feel each bout of exercise is. The first method will involve pointing to a number, picture or phrase that best describes their feelings of exertion at the time. The second method will require your child to remove a desired number of marbles from a container and place them into a second container. The easier the exercise bout feels to your child, the smaller the amount of marbles that he/she will collect from the first container. As the exercise becomes harder, a larger number of marbles will be collected from the first container. It will be made clear to each participant that there are no right or wrong answers during these tasks.

Can participants change their mind and withdraw from the project?

Participants may withdraw from the project at any time and without any disadvantage to themselves or parent / guardian of any kind.

What data or information will be collected and what use will be made of it?

Participants will have height and weight measured, and physiological data will be recorded. The subjective ratings of perceived exertion (RPE) from the E-P Scale will also be recorded.

The data collected will be securely stored and anonymised in such a way that only those within the research team will be able to gain access to it.

Results of this project may be published but any data included will in no way be linked to any specific participant.

You are most welcome to request a copy of the results of the project should you wish.

What if participants/ parents/ guardians have any questions?

If you have any questions about our project, either now or in the future, please feel free to contact either:

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(01326) 262818		(01392) 264720

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Information Sheet
(Participant)
Study 4

The perceptual response to treadmill exercise using the Eston-Parfitt Scale and marble dropping task, in children aged 7 – 8 years

Thank you for showing an interest in this study. Please read everything below before deciding if you want to take part. This information sheet will tell you a little more about the study and what we would like you to do. If you decide not to take part it will not affect your relationship with the research team or your school.

What is this project about?
This study is to find out how you feel when you exercise.

Who can take part in the study?
If you are aged 7 or 8 years old and are able to run during hard exercise you can take part in this study.

What will I have to do?
If you decide that you want to take part in this study, you will firstly be asked to visit the School of Sport and Health Sciences at the University of Exeter and take part in an exercise test. This test will involve you running on a piece of equipment called a treadmill. This test will start off quite easy, but it will get harder and harder until you will have to stop running. You may get tired and out of breath in this test, but you can stop the test whenever you want to. During this visit, you will also have your height and weight measured. When you are running, we want you to tell us how hard you think the exercise is. To help you to decide, we will show you a picture scale and then ask you to point to a number, picture or word that is most like how you feel. We will also ask you to take some marbles out of one container and put them into another container. The harder the exercise feels to you, the more marbles you take out of the container. When you are running, we will ask you to wear two bits of equipment that will measure how hard your body is working when you are exercising.

One is a belt that you will wear around your chest which measures heart rate and the other is a facemask that will collect the air that you are breathing in and out.

When will I do it?
You can take part during school time. When you visit the School of Sport and Health Sciences, you will be brought from your school by one of your teachers. Afterwards, you will be taken back to your school by your teacher. You will be away from your school for about 1 - 2 hours if you take part in this study.

Can I stop taking part if I want to?
You can stop taking part in the project at any time if you want to. No one will be cross with you if you decide to stop taking part.

What will you do with the information?
All of the information that the researchers collect will be kept on a computer and the results will be confidential to the School of Sport and Health Sciences research team. We may use the data that we collect in publications or during presentations, but no one will be able to tell which data is yours.

What if I have any questions?
If you have any questions, you can ask any member of the research team at any time.

What do I do next?
If you have read and understood everything that we will ask you to do and you would like to take part, please tick the box that say's 'I want to take part in this project' and write your name on the assent form that is attached to this sheet. Also, please ask your parent/ guardian to sign the consent form that is attached to their information sheet.

Thank you,
Danielle

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Information Sheet
(Parent / Guardian)
Study 6

Do children employ pacing strategies during field-based exercise?

Thank you for your interest in this study. Please take time to read this information sheet carefully before deciding whether or not to give your consent for your child to participate. Details about the study and what we would like to do will be given. If you decide to allow your child to participate we thank you. If you decide that you do not wish your child to take part, there will be no disadvantage to you or your child and we thank you for considering our request.

What is the aim of the project?

This project is being undertaken as part-requirement of a PhD research degree in Sport and Health Sciences. We are interested in how individuals can regulate their exercise so as to finish an exercise task, for example an 800 metre running race, in the fastest possible time without becoming completely fatigued. Several studies of this kind have been successfully conducted with adult populations. However, a child's ability to regulate exercise and pace themselves in a short-term maximal exercise effort has yet to be investigated.

Why is this important?

If children, like adults, possess the ability to accurately gauge their exercise effort merely through tuning in to their 'effort sense' or their *feelings* of exertion then it would be likely that children will also be able to produce appropriate levels of exercise to enhance health benefits and promote exercise adherence, such as in adults.

What type of participant is needed?

If your child is generally active, i.e. regularly participates in P.E. lessons / is physically active during lunch breaks or after school, and is aged between 9 – 11 years old, with no known medical conditions then they can take part in this study. If your child does not conform to the above criteria then they will be unable to take part in this research study.

What will participants be asked to do?

School of Sport and Health Sciences:

Each child will be asked to complete five exercise sessions. The first session will involve an exercise test on a treadmill (used for indoor running), and will be conducted in the exercise physiology laboratory at the School of Sport and Health Sciences at the University of Exeter. For this session, your child will be collected individually from his/her school by two of the researchers involved in this study and driven to the University. Following completion of the exercise test, your child will be returned to his/her school by the researchers. This exercise test will involve your child running to volitional exhaustion, following a standardised protocol. Volitional exhaustion means that your child may stop the exercise test at any point. This session is a familiarisation trial to get your child used to the various measures and equipment that will be used in the subsequent exercise tests, which includes a heart rate monitor (a belt which is worn around the chest) and an accelerometer (a device that measures physical activity / movement and is worn on a belt around the waist). Your child should be away from their school for approximately 1.5 hours during this session.

Outdoor grass pitch:

Sessions two to four will be completed on the outdoor grass pitch at your child's school, and children can take part during school time. On the first of these sessions, your child will be collected from his/her school classroom by two of the researchers and taken outside to the grass pitch. The measures and equipment that will be used that day will then be explained to your child. The event distance that they will be asked to run is 800 metres, or twice around a marked running track.

As children will be asked to complete the event in as fast as possible time, the exercise task itself will be quite physically demanding and your child will likely get tired and out of breath participating. To ensure your child is physically ready to undertake the exercise task, each participant will complete a warm-up, consisting of light jogging and appropriate stretching exercises prior to running the 800 m distance. Following the event, a cool-down will also be

implemented, again consisting of light jogging and some stretching exercises. This will help to minimise the risk of any muscular injury as a result of the 800 m run. After completion of the event, water will be provided to ensure your child remains hydrated during a recovery period. Your child will then be accompanied back to their classroom.
Each child should take no longer than 10 minutes to run the 800 m distance. Therefore, the total time that each session (second to fourth) should take is approximately 30 minutes. Sessions three and four will be comparable to session two.

The fifth session will be performed in much the same way as the previous sessions (two to four), with just one modification. Your child will again be accompanied to the outdoor grass pitch but this time with some of the other children who are participating in this study. All of these children will then run the same 800 m distance as before but in a group rather than individually. This session should last approximately 30 minutes.

Throughout each test, your child will be asked to wear a heart rate monitor and an accelerometer so that heart rate and various measures concerning movement patterns, such as the intensity of exercise, can be measured continuously. Through the use of a specially designed ratings of perceived exertion scale (known as the E-P scale, see attached diagram), your child will also be asked to rate how hard they feel each bout of exercise is by stating or pointing to a picture/phrase that best describes their feelings of exertion during each exercise session.

Can participants change their mind and withdraw from the project?
Participants may withdraw from participation in the project at any time and without any disadvantage to the child or parent/ guardian of any kind.

What data or information will be collected and what use will be made of it?
Participants will have their height and weight measured. Various physiological data (i.e. heart rate, breathing rate and oxygen uptake) and data obtained from the accelerometers (i.e. exercise intensity) will be recorded, as well as participants' responses according to the ratings of perceived exertion scale (E-P scale).
The data collected will be unidentifiable to any specific participant and will be securely stored for an indefinite period in such a way that only those within the research team will be able to gain access to it.

Results of this project may be published in an academic journal, but any data included will in no way be linked to any specific participant.

You are most welcome to request a copy of the results of the project should you wish.

What if participants/ parents/ guardians have any questions?

If you have any questions about our project, either now or in the future, please feel free to contact either:

Miss Danielle Lambrick	or	Professor Roger Eston
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Information Sheet
(Participant)
Study 6

Do children employ pacing strategies during field-based exercise?

Thank you for showing an interest in this study. Please read everything below before deciding if you want to take part. This information sheet will tell you a little more about the study and what we would like you to do. If you decide not to take part it will not affect your relationship with the research team or your school.

What is this project about?
At the School of Sport and Health Sciences at the University of Exeter we are interested in the benefits of exercise for children. This study is to find out how fast you can run 800 metres, which is twice around a running track, and how hard you think it is to run this distance.

Who can take part in the study?
If you are aged between 9 – 11 years and are generally quite active, i.e. you often take part in P.E lessons, or you run around during your lunch break or after school, then you can take part in this study.

What will I have to do?
If you decide that you want to take part in this study, you will firstly be asked to visit the School of Sport and Health Sciences at the University of Exeter and take part in an exercise test. This test will involve you running for about 20 minutes at a comfortable speed on a piece of equipment called a treadmill. This test will start off quite easy, but it will get harder and harder until you will have to stop running. You may get tired and out of breath in this test, but you can stop the test whenever you want to. During this visit, you will also have your height and weight measured.
After this visit, we will ask you to take part in four more sessions that will take place at the outdoor grass pitch at your school. In these next four sessions you will be asked to run 800 metres, or twice around a marked running track, as fast as you can. You will have a full day's rest between each session. For the first three sessions, you

will be collected from your classroom by the researchers and taken to the outdoor grass pitch where you will be asked to run the 800 m distance on your own. For the fourth session, you will be collected from your classroom along with some of the other children who are also taking part in this study and taken to the outdoor grass pitch. This time you will be asked to perform the 800 m run at the same time as the other children.

When you are running we want you to tell us how hard you think it is to run. To help you to decide, we will show you a picture chart and then ask you to tell us the picture or word that is most like how you feel. We will also ask you to wear two small bits of equipment when you are running which will measure how hard your body is working when you are exercising. One measures heart rate and the other indicates how many steps you are taking. These are attached to belts that you will wear around you waist and chest.

When will I do it?
You can take part during school time. For your first session, your visit to the School of Sport and Health Sciences, you will be picked up from your school classroom by two of the researchers and taken to the University. After your exercise tests, you will be taken back to your school by the researchers. You will be away from your school for about 1.5 hours during this session. The following four sessions, you will be away from your classroom for about 30 minutes each time.

Can I stop taking part if I want to?
You can stop taking part in the project at any time if you want to, and it will not affect your relationship with the research team or your school.

What will you do with the information?
All of the information that the researchers collect will be kept on a computer and the results will be confidential to the School of Sport and Health Sciences research team.

What if I have any questions?
If you have any questions, you can ask any member of the research team at any time.

What do I do next?
If you have read and understood everything that we will ask you to do and you would like to take part, please fill out the assent form which is attached to this information sheet, and ask your parent/guardian/care giver to sign the consent form.

Thank you,
Danielle

This project has been reviewed and approved by the Ethics Committee of the School of Sport and Health Sciences

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Consent Form
Study 1

Prediction of maximal oxygen uptake from the Åstrand-Ryhming nomogram and ratings of perceived exertion

I have read the Information Sheet concerning this project and I understand what it is about. I understand that my height, weight and blood pressure will be measured, that I will be asked to complete three bike tests on two separate visits to the laboratory, and convey how I feel during each test using the Ratings of Perceived Exertion scale. I understand that I am free to request further information at any stage.

I know that:

1. My participation in the project is entirely voluntary.
2. I am free to withdraw from the project at any time without giving reason, and my relationship with either the research team or the school will in no way be affected.
3. The raw data on which the results of the project depend will be retained in secure storage.
4. The results of the project may be published but my anonymity will be preserved.

I agree to take part in this project.

Signed…………………………………...   Date…………………......

Please Print Name…………………………...

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Consent Form
Study 2

Prediction of maximal oxygen uptake from submaximal ratings of perceived exertion and heart rate during a continuous exercise test: the efficacy of RPE 13

I have read the information sheet concerning this project and I understand what it is about. The purpose of this study, and the procedures involved have been clearly explained to me, and all my questions have been satisfactorily answered. I know that I will visit the exercise physiology laboratories the School of Sport and Health Sciences two times. On the first visit, I know that I will undertake a general health assessment which will incorporate measurements of my height, weight, blood pressure, non-fasting blood glucose and total cholesterol levels. I understand that non-fasting glucose and total cholesterol will be measured via a small, largely painless fingerprick blood sample. I will then perform a graded exercise test to volitional exhaustion to establish my $\dot{V}O_2max$. This exercise test will commence at a low intensity, and will become progressively harder throughout the duration of the test. Following a 48 – 72 hour recovery, I will be required to perform a submaximal exercise test. During this test I will cycle for 6-min at a set low-moderate exercise intensity. Heart rate and my perception of exertion (RPE) will be recorded each minute.

In addition, I agree that:

1. The information I give will only be used for a completion of a research student's investigation at the School of Sport and Health Sciences, University of Exeter, and any publications that may result
2. My data will be coded and I will not be identifiable in any way
3. The data will be stored in a safe place, under 'lock and key' in a filing cabinet on the premises of the School of Sport and Health Sciences for a period of 5 years following date of collection. Data stored on a computer will be password protected.

In both instances only the researchers associated with the study will have access to the data accumulated during the study

4. I have the right to see the results and have a right to request to see the completed study
5. I have the right to withdraw from the study at any time without prejudice

I agree to take part in this project.

Signed…………………………………...   Date…………………......

Please Print Name…………………………...

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Consent Form
Study 3

The perceptual response to exercise of progressively increasing intensity in children aged 7 – 8 years: validation of a pictorial curvilinear ratings of perceived exertion scale

I have read the Information Sheet concerning this project and I understand what it is about. I understand that my child.........…………………………………….(*Insert name*) will visit the exercise physiology laboratory at the School of Sport and Health Sciences on one occasion where he/she will perform a test on a cycle ergometer to volitional exhaustion. I know that his/her height and weight will be measured during this visit. I know that he/she will be asked to wear a facemask and a heart rate monitor, and convey how he/she feels during the test according to two different measures that are designed to assess the ratings of perceived exertion. I understand that I am free to request further information at any stage.

I know that:

1. My child's participation in the project is entirely voluntary.
2. I am free to withdraw my child from the project at any time without giving reason, and my relationship with either the research team or the school will in no way be affected.
3. The raw data on which the results of the project depend will be retained in secure storage.
4. The results of the project may be published but my child's anonymity will be preserved.

I agree to my child taking part in this project.

Signed…………………………………... Date…………………......

Please Print Name…………………………...

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Assent Form
Study 3

The perceptual response to exercise of progressively increasing intensity in children aged 7 – 8 years: validation of a pictorial curvilinear ratings of perceived exertion scale

I have read the Information Sheet and I understand what it is about. I know that I will visit the School of Sport and Health Sciences and exercise on a cycle ergometer as hard, and for as long as I can. I understand that this exercise will feel easy at the start and will get harder towards the end. I know that my height and weight will be measured. I also know that I will wear a facemask and a heart rate monitor when I'm cycling, and will be asked to show how hard the exercise is by pointing to a picture scale and placing some marbles into a container.

I know that:

1. I am able to take part, only if I want to.
2. I can stop taking part at any time if I want to and I don't have to give anyone a reason why.
3. All of my results will be kept by the experimenter.
4. The results of the project may be published but no one will know which results are mine.

Please tick the box below that applies to you:

I agree to take part in this project ☐

I do not agree to take part in this project ☐

Please Print Name: ....

This project has been reviewed and approved by the Ethics Committee of the School of Sport and Health Sciences

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Consent Form
Study 4

The perceptual response to treadmill exercise using the Eston-Parfitt Scale and marble task, in children aged 7 – 8 years

I have read the Information Sheet concerning this project and I understand what it is about. I have read the Participant Information Sheet with or to my child ……………………………..... (*Insert name*), and I am satisfied that they understand what they will be required to do. I know that my child will visit the exercise physiology laboratory in the School of Sport and Health Sciences on one occasion where he/she will perform a test on a treadmill to volitional exhaustion. I know that his/her height and weight will be measured during this visit. I know that he/she will be asked to wear a facemask and a heart rate monitor, and convey how he/she feels during the test according to two different measures that are designed to assess the ratings of perceived exertion. I understand that I am free to request further information at any stage.

I know that:

1. My child's participation in the project is entirely voluntary.
2. I am free to withdraw my child from the project at any time without giving reason, and my relationship with either the research team or the school will in no way be affected.
3. The raw data on which the results of the project depend will be retained in secure storage.
4. The results of the project may be published but my child's anonymity will be preserved.

I agree to my child taking part in this project.

Signed…………………………………...   Date…………………......

Please Print Name…………………………...

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Assent Form
Study 4

The perceptual response to treadmill exercise using the Eston-Parfitt Scale and marble dropping task, in children aged 7 – 8 years

I understand what I will have to do if I take part in this study. I know that I will visit the School of Sport and Health Sciences and exercise on a treadmill as hard, and for as long as I can. I understand that this exercise will feel easy at the start and will get harder towards the end. I know that my height and weight will be measured. I also know that I will wear a facemask and a heart rate monitor when I'm running, and will be asked to show how hard the exercise is by pointing to a picture scale and placing some marbles into a container.

I know that:

1. I am able to take part, only if I want to.
2. I can stop taking part at any time if I want to and I don't have to give anyone a reason why.
3. All of my results will be kept by the experimenter.
4. The results of the project may be published but no one will know which results are mine.

Please tick the box below that applies to you:

I agree to take part in this project ☐

I do not agree to take part in this project ☐

Please Print Name: ....

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Consent Form
Study 6

Do children employ pacing strategies during field-based exercise?

I have read the Information Sheet concerning this project and I understand what it is about. I have read the Participant Information Sheet with or to my child ……………………………..... (*Insert name*), and I am satisfied that they understand what they will be required to do. I know that my child will visit the exercise physiology laboratory in the School of Sport and Health Sciences on one occasion where he/she will perform a test on a treadmill to volitional exhaustion. I know that his/her height and weight will be measured during this visit. I know that he/she will be asked to complete an 800 metre run on four separate occasions, which will take place at the outdoor grass pitch at my child's school. Also, that during each of these tests, my child will be required to wear a heart rate monitor and an accelerometer, and convey how he/she feels during each test according to a specially designed pictorial scale to assess the ratings of perceived exertion. I understand that I am free to request further information at any stage.

I know that:

1. My child's participation in the project is entirely voluntary.
2. I am free to withdraw my child from the project at any time without giving reason, and my relationship with either the research team or the school will in no way be affected.
3. The raw data on which the results of the project depend will be retained in secure storage.
4. The results of the project may be published but my child's anonymity will be preserved.

I agree to my child taking part in this project.

Signed………………………………….... Date……………………......

Please Print Name…………………………...

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Assent Form

Study 6

Do children employ pacing strategies during field-based exercise?

I have read the Information Sheet and I understand what it is about. I understand that I will visit the School of Sport and Health Sciences and run on a treadmill as hard, and for as long as I can. I know that my height and weight will be measured, and I will be asked to wear two bits of equipment on a belt around my chest and waist. I know that I will be asked to run 800 metres on the outdoor grass pitch at Ladysmith Junior School as fast as I can on four separate occasions (once, on four different days). I will also be asked to show how hard each race is by reading a number off a picture scale.

I know that:

1. I am able to take part, only if I want to.
2. I can stop taking part at any time if I want to and I don't have to give anyone a reason why.
3. All of my results will be kept by the experimenter.
4. The results of the project may be published but no one will know which results are mine.

Please tick the box below that applies to you:

I agree to take part in this project ☐

I do not agree to take part in this project ☐

Please Print Name: ....

This project has been reviewed and approved by the Ethics Committee of the School of Sport and Health Sciences

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SSHS General Health Questionnaire

Your Name: ……………………………………………………………………

Your Date of Birth: ……………………………………………………………

Male / Female (please circle)

Your Height: …………… Your Weight: …………………

Your Address: ………………………………………………………………

………………………………………………………………

………………………………………………………………

Your Phone No.: ……………………………………………………………………

Name of person responsible for study: …………………………………..

Please read the following carefully and answer as accurately as possible. The questions are designed solely to determine whether the proposed exercise is appropriate for you. Your answers will be treated as strictly confidential. If you have any doubts or difficulties with any of the questions please contact the person responsible for the study.

1.	Have you seen your doctor in the last 6 months?	YES	NO
2.	Are you currently taking any prescription medications?	YES	NO
3.	Has a doctor ever said you have heart trouble?	YES	NO
4.	Do you ever feel chest pain when you undertake physical activity?	YES	NO
5.	Do you ever feel faint or have spells of dizziness?	YES	NO
6.	Do you experience unreasonable breathlessness?	YES	NO
7.	Do you take heart medications?	YES	NO
8.	Has a doctor ever said you have epilepsy?	YES	NO
9.	Has a doctor ever said you have diabetes?	YES	NO
10.	Has a doctor ever said you have asthma or other lung disease?	YES	NO
11.	Do you have a bone, joint or muscular problem which may be aggravated by exercise?	YES	NO

12. Do you have any form of injury?	YES	NO
13. Has a doctor ever said you have high blood pressure?	YES	NO
14. Has a doctor ever said you have high cholesterol?	YES	NO
15. Do you have a close blood relative who had a heart attack or heart surgery before age 55 (father or brother) or age 65 (mother or sister)?	YES	NO
16. Do you smoke, or have you quit smoking in the last 6 months?	YES	NO
17. Do you get more than 30 minutes of physical activity on at least 3 days per week?	YES	NO
18. If you are female, are you pregnant?	YES	NO

I have completed the questionnaire to the best of my knowledge and any questions that I have raised have been answered to my full satisfaction.

Signed: …………………………………………………………..

Date: ……………………………

Appendix 4.

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Current Health Status Questionnaire for males up to 45 years of age and females up to 55 years of age

This form is to be used in conjunction with the SSHS General Health Questionnaire. It is to be completed in the laboratory prior to the commencement of the exercise test.

		YES	NO
1.	Have you suffered from a viral illness in the last two weeks?		
2.	Have you eaten within the last hour?		
3.	Have you consumed alcohol within the last 24 hours?		
4.	Have you performed exhaustive exercise within the last 48 hours?		
5.	Is there anything to your knowledge that may prevent you from successfully completing the tests that have been outlined to you?		

I have completed the questionnaire to the best of my knowledge and any questions that I have raised have been answered to my full satisfaction.

Signed: ……………………………………………………..

Date: …………………………..

The Keele Lifestyle (RPE) Nomogram for predicting $\dot{V}O_2max$ from RPE during submaximal ergometer cycling. Published with permission from the Taylor & Francis Group, Routledge Journals. From Buckley et al. (1998). The development of a nomogram for predicting $\dot{V}O_2max$ from ratings of perceived exertion during submaximal exercise on a cycle ergometer. *Journal of Sports Sciences,* 16, pp. 15.

	Pr $\dot{V}O_2max$	**Cycle work rates (W)**																				
RPE	**(L·min^{-1})**	**30**	**40**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**100**	**105**	**110**	**120**	**130**	**140**	**150**	**160**	**170**	**180**
9	**0.5**	1.01	1.3	1.62	1.76	1.91	2.08	2.23	2.37	2.54	2.69	2.83	3.15	3.3	3.44	3.76	4.05	4.37	4.68	4.97	5.29	5.58
10	**0.55**	0.92	1.2	1.48	1.62	1.75	1.89	2.03	2.17	2.31	2.45	2.59	2.87	3.01	3.15	3.42	3.7	3.98	4.26	4.54	4.81	5.09
11	**0.6**	0.84	1.1	1.36	1.49	1.62	1.74	1.87	2	2.13	2.25	2.37	2.63	2.76	2.89	3.15	3.4	3.65	3.9	4.16	4.42	4.68
12	**0.65**	0.79	1.03	1.26	1.38	1.5	1.62	1.73	1.85	1.97	2.09	2.2	2.44	2.56	2.67	2.91	3.15	3.38	3.62	3.85	4.09	4.32
13	**0.7**	0.74	0.96	1.18	1.28	1.39	1.51	1.62	1.72	1.83	1.95	2.05	2.27	2.37	2.49	2.71	2.92	3.15	3.36	3.58	3.8	4.01
14	**0.75**	0.69	0.9	1.1	1.21	1.3	1.41	1.51	1.62	1.71	1.82	1.91	2.13	2.23	2.33	2.54	2.74	2.94	3.15	3.35	3.55	3.76
15	**0.8**	0.66	0.84	1.04	1.13	1.23	1.33	1.42	1.52	1.62	1.71	1.81	2.0	2.1	2.18	2.37	2.57	2.76	2.95	3.15	3.34	3.52
16	**0.85**	0.62	0.8	0.98	1.07	1.17	1.25	1.35	1.43	1.53	1.62	1.7	1.88	1.98	2.06	2.25	2.43	2.6	2.78	2.96	3.15	3.33
17	**0.9**	0.6	0.77	0.93	1.02	1.1	1.19	1.27	1.36	1.44	1.53	1.62	1.79	1.87	1.96	2.13	2.29	2.46	2.62	2.8	2.97	3.15
18	**0.95**	0.57	0.73	0.89	0.97	1.05	1.13	1.21	1.29	1.37	1.45	1.43	1.69	1.78	1.85	2.02	2.18	2.34	2.5	2.66	2.82	2.98
19	**1.0**	0.55	0.69	0.84	0.93	1.01	1.08	1.16	1.23	1.3	1.38	1.47	1.62	1.69	1.76	1.91	2.08	2.23	2.37	2.54	2.69	2.83

Instruction: Read down the left-hand column to the RPE given during the sixth minute of the exercise test and then across to the column of the cycle work rate. For example, an RPE of 12 at 90 W gives an estimated $\dot{V}O_2max$ of 2.2 L·min^{-1}.

Note: The nomogram is based on the following equation: Predicted $\dot{V}O_2max$ = (WR / 70) / (pr$\dot{V}O_2max$: RPE)

Where WR is the cycle work rate in watts, 70 is a constant oxygen cost ($\dot{V}O_2$) for ergometer cycling of 70 W·L^{-1}·min^{-1} (Åstrand & Rodahl, 1986, *Textbook of Work Physiology*. New York: McGraw-Hill), and pr$\dot{V}O_2max$: RPE is the proportion of $\dot{V}O_2max$ represented by the RPE after 6 min of the cycle test.

A subsequent regression equation corrects the difference between measured- and predicted scores: Corrected Predicted $\dot{V}O_2max = 1.076x + 0.085$ Where x is the predicted $\dot{V}O_2max$ calculated from the earlier stated predictive equation.

Transformation of r to Z_r

Table used for transformation of correlation coefficients (r) to a Fisher Z_r transformation value.

r	Z_r	r	Z_r	r	Z_r
0.000	0.000	0.340	0.354	0.680	0.829
0.010	0.010	0.350	0.365	0.690	0.848
0.020	0.020	0.360	0.377	0.700	0.867
0.030	0.030	0.370	0.388	0.710	0.887
0.040	0.040	0.380	0.400	0.720	0.908
0.050	0.050	0.390	0.412	0.730	0.929
0.060	0.060	0.400	0.424	0.740	0.950
0.070	0.070	0.410	0.436	0.750	0.973
0.080	0.080	0.420	0.448	0.760	0.996
0.090	0.090	0.430	0.460	0.770	1.020
0.100	0.100	0.440	0.472	0.780	1.045
0.110	0.110	0.450	0.485	0.790	1.071
0.120	0.121	0.460	0.497	0.800	1.099
0.130	0.131	0.470	0.510	0.810	1.127
0.140	0.141	0.480	0.523	0.820	1.157
0.150	0.151	0.490	0.536	0.830	1.188
0.160	0.161	0.500	0.549	0.840	1.221
0.170	0.172	0.510	0.563	0.850	1.256
0.180	0.182	0.520	0.576	0.860	1.293
0.190	0.192	0.530	0.590	0.870	1.333
0.200	0.203	0.540	0.604	0.880	1.376
0.210	0.213	0.550	0.618	0.890	1.422
0.220	0.224	0.560	0.633	0.900	1.472
0.230	0.234	0.570	0.648	0.910	1.528
0.240	0.245	0.580	0.662	0.920	1.589
0.250	0.255	0.590	0.678	0.930	1.658
0.260	0.266	0.600	0.693	0.940	1.738
0.270	0.277	0.610	0.709	0.950	1.832
0.280	0.288	0.620	0.725	0.960	1.946
0.290	0.299	0.630	0.741	0.970	2.092
0.300	0.310	0.640	0.758	0.980	2.298
0.310	0.321	0.650	0.775	0.990	2.647
0.320	0.332	0.660	0.793		
0.330	0.343	0.670	0.811		

Modified from Thomas & Nelson (1996), *Research methods in physical activity*, Leeds: Human Kinetics, p. 432.

Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	**Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	2.	**Do you feel pain in your chest when you do physical activity?**
☐	☐	3.	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	4.	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	5.	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	6.	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	7.	**Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ______________________________

SIGNATURE ______________________________ DATE ______________________________

SIGNATURE OF PARENT ______________________________ WITNESS ______________________________
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

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...continued from other side

PAR-Q & YOU

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

CANADA'S **Physical Activity Guide** to Healthy Active Living

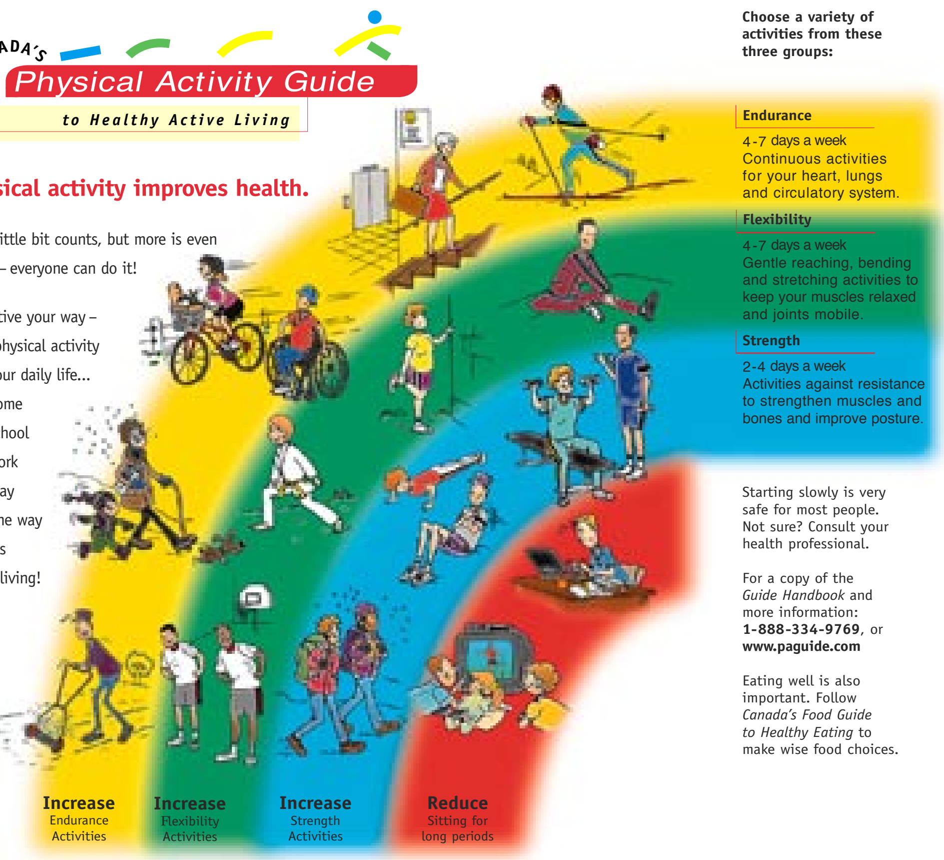
Physical activity improves health.

Every little bit counts, but more is even better – everyone can do it!

Get active your way – build physical activity into your daily life...

- at home
- at school
- at work
- at play
- on the way

...that's active living!



Choose a variety of activities from these three groups:

Endurance
4-7 days a week
Continuous activities for your heart, lungs and circulatory system.

Flexibility
4-7 days a week
Gentle reaching, bending and stretching activities to keep your muscles relaxed and joints mobile.

Strength
2-4 days a week
Activities against resistance to strengthen muscles and bones and improve posture.

Starting slowly is very safe for most people. Not sure? Consult your health professional.

For a copy of the *Guide Handbook* and more information: **1-888-334-9769**, or **www.paguide.com**

Eating well is also important. Follow *Canada's Food Guide to Healthy Eating* to make wise food choices.

Get Active Your Way, Every Day – For Life!

Scientists say accumulate 60 minutes of physical activity every day to stay healthy or improve your health. As you progress to moderate activities you can cut down to 30 minutes, 4 days a week. Add-up your activities in periods of at least 10 minutes each. Start slowly… and build up.

Time needed depends on effort

Very Light Effort	Light Effort *60 minutes*	Moderate Effort *30-60 minutes*	Vigorous Effort *20-30 minutes*	Maximum Effort
• Strolling • Dusting	• Light walking • Volleyball • Easy gardening • Stretching	• Brisk walking • Biking • Raking leaves • Swimming • Dancing • Water aerobics	• Aerobics • Jogging • Hockey • Basketball • Fast swimming • Fast dancing	• Sprinting • Racing
	Range needed to stay healthy			

You Can Do It – Getting started is easier than you think

Physical activity doesn t have to be very hard. Build physical activities into your daily routine.

- Walk whenever you can – get off the bus early, use the stairs instead of the elevator.
- Reduce inactivity for long periods, like watching TV.
- Get up from the couch and stretch and bend for a few minutes every hour.
- Play actively with your kids.
- Choose to walk, wheel or cycle for short trips.
- Start with a 10 minute walk – gradually increase the time.
- Find out about walking and cycling paths nearby and use them.
- Observe a physical activity class to see if you want to try it.
- Try one class to start – you don t have to make a long-term commitment.
- Do the activities you are doing now, more often.

Benefits of regular activity:	Health risks of inactivity:
• better health • improved fitness • better posture and balance • better self-esteem • weight control • stronger muscles and bones • feeling more energetic • relaxation and reduced stress • continued independent living in later life	• premature death • heart disease • obesity • high blood pressure • adult-onset diabetes • osteoporosis • stroke • depression • colon cancer

Health Canada Santé Canada

Canadian Society for Exercise Physiology

ACTIVE LIVING

CANADA'S Physical Activity Guide to Healthy Active Living

Source: Canada's Physical Activity Guide to Healthy Active Living, Health Canada, 1998 http://www.hc-sc.gc.ca/hppb/paguide/pdf/guideEng.pdf

FITNESS AND HEALTH PROFESSIONALS MAY BE INTERESTED IN THE INFORMATION BELOW:

The following companion forms are available for doctors' use by contacting the Canadian Society for Exercise Physiology (address below):

The **Physical Activity Readiness Medical Examination (PARmed-X)** – to be used by doctors with people who answer YES to one or more questions on the PAR-Q.

The **Physical Activity Readiness Medical Examination for Pregnancy (PARmed-X for Pregnancy)** – to be used by doctors with pregnant patients who wish to become more active.

References:
Arraix, G.A., Wigle, D.T., Mao, Y. (1992). Risk Assessment of Physical Activity and Physical Fitness in the Canada Health Survey Follow-Up Study. **J. Clin. Epidemiol.** 45:4 419-428.
Mottola, M., Wolfe, L.A. (1994). Active Living and Pregnancy, In: A. Quinney, L. Gauvin, T. Wall (eds.), **Toward Active Living: Proceedings of the International Conference on Physical Activity, Fitness and Health**. Champaign, IL: Human Kinetics.
PAR-Q Validation Report, British Columbia Ministry of Health, 1978.
Thomas, S., Reading, J., Shephard, R.J. (1992). Revision of the Physical Activity Readiness Questionnaire (PAR-Q). **Can. J. Spt. Sci.** 17:4 338-345.

For more information, please contact the:

Canadian Society for Exercise Physiology
202-185 Somerset Street West
Ottawa, ON K2P 0J2
Tel. 1-877-651-3755 • FAX (613) 234-3565
Online: www.csep.ca

The original PAR-Q was developed by the British Columbia Ministry of Health. It has been revised by an Expert Advisory Committee of the Canadian Society for Exercise Physiology chaired by Dr. N. Gledhill (2002).

Disponible en français sous le titre «Questionnaire sur l'aptitude à l'activité physique - Q-AAP (revisé 2002)».

Supported by: Health Canada Santé Canada

RISK FACTOR COUNTING AND INTERPRETATION FOR EXERCISE TESTING AND EXERCISE PRESCRIPTION

	Enter 1 for Yes, 0 for No
Family history *	
Current smoker or smoker in last six months	______
SBP ≥ 140 *or* DBP ≥ 90 mmHg	______
Total cholesterol $\geq 5.2\ \text{mmol}\cdot\text{l}^{-1}$	______
Fasting blood glucose $\geq 6.1\ \text{mmol}\cdot\text{l}^{-1}$ †	______
BMI ≥ 30, or waist girth > 102 cm in men or > 88 cm in women ‡	______
Sedentary §	______
Age > 45 if male or > 55 if female	______
Sum of positive risk factors (A):	☐
HDL-C > $1.6\ \text{mmol}\cdot\text{l}^{-1}$	______
Negative risk factor count (B):	☐
Risk factor score (A+B)	☐

* Family history refers to heart attack in father or brother before age 55 or mother or sister before age 65.
† Impaired fasting glucose should be confirmed by measurements on at least two separate occasions.
‡ Waist girth should be measured with an inelastic tape in a horizontal plane at the narrowest part of the torso.
§ Sedentary refers to individuals not engaged in a regular exercise programme or those not undertaking 30 min of moderate-intensity physical activity on three or more days of the week.

Interpretation:
Low-risk individuals are asymptomatic men ≤45 years and asymptomatic women ≤55 years whose risk factor score is no more than one. Low-risk individuals can undergo a maximal exercise test and participate in vigorous exercise training.
Moderate-risk individuals are asymptomatic men >45 years, asymptomatic women >55 years, and, regardless of age, individuals whose risk factor score is two or more. 'Moderate-risk' individuals can undergo a sub-maximal exercise test and can begin a programme of moderate-intensity exercise.
High-risk individuals are those with signs or symptoms of heart disease, as indicated by any 'yes' answer on the PAR-Q. High-risk individuals should consult their GP before engaging in exercise testing or exercise training.

HEALTH SCREENING FOR CHILD VOLUNTEERS (PARENTAL FORM)

Name: ....

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:

1. To ensure their own continuing well-being.
2. To avoid the possibility of individual health issues confounding study outcomes.

Your answer to the questions in this questionnaire, on behalf of your child, are **strictly confidential.**

Please complete this brief questionnaire to confirm your child's fitness to participate:

1. **At present**, does your child have any health problem for which they are:
   a. On medication, prescribed or otherwise.................. Yes No
   b. Attending a general practitioner.............................. Yes No
   c. On a hospital waiting list... Yes No
2. **In the past two years**, has your child had any illness that required them to:
   a. Consult your family GP.. Yes No
   b. Attend a hospital outpatient department................ Yes No
   c. Be admitted to hospital.. Yes No
3. **Has your child ever** had any of the following:
   a. Convulsions.. Yes No
   b. Asthma... Yes No
   c. Eczema.. Yes No
   d. Diabetes.. Yes No
   e. A blood disorder... Yes No
   f. Head injury.. Yes No
   g. Digestive problems... Yes No
   h. Heart problems.. Yes No
   i. Problems with bones or joints................................. Yes No
   j. Disturbance of balance/coordination...................... Yes No
   k. Numbness in hands or feet...................................... Yes No
   l. Disturbance of vision.. Yes No
   m. Ear / hearing problems.. Yes No
   n. Thyroid problems.. Yes No
   o. Kidney or liver problems.. Yes No
   p. Allergy to nuts.. Yes No

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

Thank you for your cooperation

SCHOOL OF SPORT AND HEALTH SCIENCES
St. Luke's Campus
Heavitree Road
EXETER
EX1 2LU

Telephone 01392 262818
Fax 01392 264706
Email D.M.Lambrick@ex.ac.uk
Web www.ex.ac.uk/sshs

Dear Parents / Guardians,

Re. The use of photographs of children participating in the perceived exertion study at the School of Sport and Health Sciences, University of Exeter

Thank you for allowing your child to participate in the above study.

During the data collection period, we take a few photographs of the experimental procedures. The use of photographs to document various methods and procedures involved in an academic research study is common within the research community. Photographs can be very informative, and are frequently used during conference presentations or within the written thesis of a PhD student to help guide the reader through the nature of the study.

Given the quite obvious misgivings a parent / guardian may have regarding their child being photographed, this letter aims to address some of the more common concerns and provide you with the opportunity to consider our request:

With prior written permission from parents / guardians, we would like to take some photographs of your child while he/she is participating in the study. Specifically, this would be when your child is running on the treadmill during the exercise test, or when running around the grass pitch at your child's school.

All photographs will be subject to the following conditions:

1. Parents / guardians understand that photos may be used for research purposes.
2. Photographs may be used for publication purposes, but only after explicit consent from the appropriate parent / guardian.
3. No photographs will be used on the internet for PR purposes unless explicitly specified by the parent / guardian.
4. No personal or identifiable information (i.e. name, date-of-birth) will be linked with any photograph.

Please indicate (using the tick box) if you give consent to the use of photos of your child, under the above conditions:

☐ *I give my consent under the conditions listed, for photographs to be taken of my child during his/her exercise sessions.*

☐ *I do not give my consent for the use of photographs of my child.*

Please state in the box provided if you wish to provide consent for the use of photographs of your child but have further stipulations that you wish to be adhered to:

Please read the following information with or to your child so that they may provide informed assent to the use of photography during their exercise session.

Participant Assent:

We would like to take some photographs of you when you are taking part in the exercise study. This would be either when you are running on the treadmill at the School of Sport and Health Sciences, or when you are running around the grass pitch at your school.

1. We use these photographs to show people exactly how we have carried out this research study.
2. None of the photographs that we take will have any personal information, such as your name, attached to them.
3. You can ask not to have your photograph taken at any point during the research study.

Please indicate by ticking the appropriate box below if you are happy to have your photograph taken during the research study:

☐ *I agree to have my photograph taken during my exercise sessions.*

☐ *I do not agree to have my photograph taken.*

Thank you for considering this request.