CHAPTER 1

INTRODUCTION & LITERATURE REVIEW
1.0 Introduction

The measurement of maximal oxygen uptake ($\dot{V}O_{2\text{max}}$) is accepted as the criterion measure of the functional capacity of an individual’s cardio-respiratory system (ACSM, 2006; Heyward, 2006). As the product of maximal cardiac output (L blood·min$^{-1}$) and arterial-venous oxygen difference (($a$-$\bar{v}$)O$_2$ diff), $\dot{V}O_{2\text{max}}$ reflects both the capacity of the heart, lungs and blood to transport oxygen to the working muscles, as well as the muscles’ ability to utilize that oxygen during exercise (ACSM, 2006; Heyward, 2006).

Therefore, $\dot{V}O_{2\text{max}}$ is the most valid measure of fitness available to health practitioners and sport and exercise scientists. Thus, $\dot{V}O_{2\text{max}}$ values present a desirable method of assessing the fitness of a variety of populations from elite athletes to clinical patients, providing sound baseline data by which to monitor, regulate and if necessary adapt training and exercise intensities.

Modern automated systems provide accurate and easily operable measures of $\dot{V}O_{2\text{max}}$ assessment, however all maximal testing procedures should be performed under the supervision of a trained health/medical professional as maximal testing can cause dyspnea, panting, leg pain and fatigue (ACSM, 2006).

However, $\dot{V}O_{2\text{max}}$ testing is not always a feasible option when attempting to determine an individual’s level of fitness. For example, clinical patients and elite athletes may be two populations who are ineligible to perform maximal fitness tests due to the risk of physiological trauma, injury, or worse (Dick, 2003; ACSM, 2006).

To this end, indirect methods of predicting maximal fitness ($\dot{V}O_{2\text{max}}$) from sub-maximal exercise have been devised over time, such as the Åstrand-Rhyming cycle
test, the Multistage Fitness test and the Chester step test, which have all used measures of heart rate to estimate an individual’s $V_{O2\text{max}}$ (Åstrand & Ryhming, 1954; Margaria, Adhemo & Rouelli, 1965; Miyashita, Mutoh, Yoshioka & Sadamoto, 1985; Brewer, Ramsbottom & Williams, 1988; Sykes, 2005).

However, the validity of such methods is questionable as heart rate has been proven to be affected by numerous factors such as medication and environmental temperature (Gutmann, Squires, Pollock, Foster & Anholm, 1981; Pollock, Jackson & Foster, 1986; Van Baak, 1988; Van Baak, Koene & Verstappen, 1988; Eston & Connolly, 1996; Eston & Thompson, 1997; Kurokochi, 2001).

Therefore, the use of sub-maximal, perceptually regulated, graded exercise testing has been advocated as a method of predicting $V_{O2\text{max}}$ that provides better agreement with actual $V_{O2\text{max}}$ than previous predictive methods based on heart rate (Eston, Lamb, Parfitt & King, 2005; Eston, Faulkner, Mason & Parfitt, 2006).

Thus, it has been proposed that Borg’s 15-point Ratings of Perceived Exertion (RPE) Scale provides a medium by which subjective interpretations of different levels of exercise intensity may be moderated, and hence provide an acceptable basis for accurately predicting $V_{O2\text{max}}$ at the highest grade of RPE intensity.

1.1 Perceived Exertion

Every individual perceives exertion (Noble & Robertson, 1996). From day to day tasks, to active recreation, and to elite endurance sport, levels of physical strain and exertion are indiscriminately subjected to psychophysical self-appraisal (Borg, 1998).
Therefore, perceived exertion can be defined as “the act of detecting and interpreting sensations arising from the body during physical exertion” (Noble & Robertson, 1996:4).

A person’s perception of physical exertion allows them to monitor feelings of exercise intensity by sensory feedback; such internal feedback allows an individual to pace themselves appropriately during a specific bout of exercise or physical activity (Noble & Robertson, 1996).

Through experience and internal feedback an individual develops a subliminal capacity for exercise and effort tolerance, this capacity allows that person to interpret and categorise varying levels of strain and exertion (Noble & Robertson, 1996). Such internal and subliminal interactions are often taken for granted, or are overlooked by the individual experiencing them, but these associations allow a person to self-regulate effort intensity within their perceived comfort zone or beyond, thus determining factors such as exercise duration and pain threshold (Borg, 1998; Noble & Robertson, 1996).

It is stated that sensations of exertion become stronger and more apparent with increasing intensity, to the point where tasks or activities start to feel difficult or physically challenging (Buckley, Sim, Eston, Hession & Fox, 2004).

The concept of ‘perceived exertion’ was coined over 40 years ago by the esteemed Swedish psychologist, Gunnar Borg (Buckley, Holmes & Mapp, 1999). Borg’s early work revolved around the development of a universal rating scale both practical and accurate in measuring perceptual intensity in-line with physiological markers of
exercise intensity (Borg, 1998; Buckley, Holmes & Mapp, 1999; Buckley & Eston, 2007). Borg proposed that the development of a subjective categorical medium, running parallel to physiological markers of physical effort would enhance both understanding of the internal mechanisms by which individuals adapt to physical exercise, as well as the interpretations that they attach to particular sensations (Noble & Robertson, 1996; Buckley & Eston, 2007).

1.2 Rationale for Study

Previously, indirect methods of predicting VO2max have been developed by measuring heart rate during sub-maximal exercise in order to prescribe safe and health positive exercise without having to test clinical patients to exhaustion (Åstrand & Ryhming, 1954; Margaria, Adhemo & Rouelli, 1965; Miyashita, Mutoh, Yoshioka & Sadamoto, 1985).

However, heart rate can be affected by factors unrelated to physical exertion such as environmental temperature, humidity, medical condition and medication (beta blockade and caffeine); for example, Eston and Connolly (1996) and Eston and Thompson (1997) state that beta-blockade causes a 20-30% reduction in HR. Moreover, hypertensive patients suffering from tachycardia average resting HRs of between 110 to 130bpm (Kurokochi, 2001; Van Baak, 1988; Van Baak, Koene & Verstappen, 1988). Also, diabetic patients may develop autonomic neuropathy which causes regular fluctuations in HR, contributing to a condition termed heart rate variability (Malpos & Maling, 1990; Osterhues, Grossman, Kochs & Hombach, 1998).
Hence, the validity of such methods has been questioned as it would appear inappropriate to prescribe exercise based on a fixed low level HR (for example 120bpm) for cardio-selective and diabetic patients (Gutmann, Squires, Pollock, Foster & Anholm, 1981; Pollock, Jackson & Foster, 1986).

Therefore, the conventional method of predicting \( \dot{V}O_{2\text{max}} \) by estimating maximal heart rate (HR\(_{\text{max}}\)) from the 220-age calculation can be seen to be flawed when considering its use with certain clinical patients or under particular environmental conditions (Mertens, Kavanagh, & Shephard, 1994).

To this end, the usefulness of HR alone as a measure of physiological intensity is dubious when exposed to a plethora of environmental and medical circumstances and conditions; consequently, alternative methods of estimating \( \dot{V}O_{2\text{max}} \) have been sought, with Ratings of Perceived Exertion (RPE) frequently alluded to as a desirable, dependent mediator (Pollock, Jackson & Foster, 1986; Borg, 1998; Eston et al., 2005; Eston et al., 2006).

Hence, previous studies have attempted to predict \( \dot{V}O_{2\text{max}} \) by extrapolating RPE equated data from sub-maximal estimation trials (Okura & Tanaka, 2001). Following such research, recent studies have accurately predicted \( \dot{V}O_{2\text{max}} \) from sub-maximal, perceptually regulated exercise tests during cycle ergometry (Eston et al., 2008; Faulkner et al., 2007; Eston et al., 2006; Eston et al., 2005). However, there is no literature investigating the agreement between \( \dot{V}O_{2\text{max}} \) values obtained from a maximal graded exercise test and those predicted from perceptually regulated, sub-maximal tests using a treadmill. Production of valid \( \dot{V}O_{2\text{max}} \) values from repeated sub-maximal and self-regulated exercise tests using a treadmill would lend strong
support to the findings presented in similar studies using cycle ergometry, thus providing further endorsement for an RPE guided method of $\dot{V}O_{2\text{max}}$ prediction and exercise prescription. Also, successful validation of the treadmill modality would provide healthy individuals, patients and health professional’s greater variety when selecting a suitable exercise mode.

### 1.3 Aim

To assess the validity and repeatability of predicting acceptable estimates of $\dot{V}O_{2\text{max}}$ from sub-maximal intensities corresponding to the perceptual RPE grades of 9, 11, 13, and 15.

As aforementioned, previous studies have attempted to predict $\dot{V}O_{2\text{max}}$ by extrapolating RPE equated data from sub-maximal estimation trials (Okura & Tanaka, 2001). Following such research, more recent studies have accurately predicted $\dot{V}O_{2\text{max}}$ from sub-maximal, perceptually regulated exercise tests, however these methods have only been performed using a cycle ergometer (Eston et al., 2008; Faulkner et al., 2007; Eston et al., 2006; Eston et al., 2005). This will be the first study to assess if such a method can be used on a treadmill.

### 1.4 Hypothesis

Maximal oxygen uptake can be predicted with acceptable agreement and reliability from perceptually regulated sub-maximal exercise.

Also, predictive accuracy would improve over successive trials.

### 1.5 Literature Review
1.5.1 Ratings of Perceived Exertion and the Borg RPE Scale

A rating of perceived exertion (RPE) enables an individual to elucidate a subjective self-interpretation of the sensations of effort, strain, discomfort and/or fatigue experienced within the body during an episode of physical exertion, and thus be aligned with objective physiological measurements of that bout of exertion (Borg, 1998; Buckley, Holmes & Mapp, 1999; Robertson et al., 2000).

Uses of such rating scales communicate an effective psychophysical self-evaluation linking an individual’s perceptual and physiological responses to exercise intensity in local and/or central exertion (Ekblom & Goldberg, 1971; cited in Borg, 1998; Borg, 2001).

To this degree, Robertson (2001) likens the stimulus-response (S-R) element of correlating feelings of exertion to outlined descriptors of increasing intensity to a gestalt-like response, as both internal and external cues are simultaneously processed in order to shape a perception of the current level of physical exertion.

Therefore, Borg (1998:8) explains that the concept of perceived exertion refers to heavy muscular work evoking a relative level of strain or intensity on the musculoskeletal, cardiovascular and pulmonary systems.

Buckley, Holmes and Mapp (1999) state that the use of RPE as a tool of exercise testing and analysis has become as widely accepted as heart rate, as a marker of physiological intensity.

RPE is commonly employed in the areas of occupational/ergonomic work studies, elitist and paediatric sport and exercise testing, it is also a popular tool used in clinical settings to assess fitness and subsequently monitor and prescribe safe and
effective levels of exercise/physical activity for training or rehabilitation purposes (Borg, 2001; ACSM, 2006; Buckley & Eston, 2007; Gearhart, 2008).

The concept of perceived exertion has evolved from the 1950s, its progression as a measurement variable in exercise testing can strongly be attributed to the work of Gunnar Borg who developed the “Borg’s 15-point RPE scale” (Buckley, Holmes & Mapp, 1999; Borg, 2001). Borg developed the RPE scale (figure 1.1) to satisfy demand for a valid and reliable scale that could be applied in exercise testing, a scale capable of corresponding actual physiological exertion with subjective feelings of that level of exertion in order to determine and regulate appropriate/effective exercise intensity (Borg, 2001; Buckley & Eston, 2007).

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<tr>
<td>6</td>
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<td>7</td>
<td>Extremely light</td>
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<td>9</td>
<td>Very light</td>
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<td>11</td>
<td>Light</td>
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<td>12</td>
<td>Somewhat hard</td>
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<td>20</td>
<td>Maximal Exertion</td>
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Borg, 1998
On this 15-point RPE scale (figure 1.1), a range of selected numbers are anchored with verbal expressions such as “Very light”, “Light”, “Somewhat Hard” and “Hard (heavy)” to facilitate the participant’s interpretation of their perceived level of exertion and portrayal of their S-R function (Borg, 1998, 2001).

As aptly articulated by Buckley and Eston (2007), the RPE scale acts as a surrogate or concurrent marker of significant physiological responses brought about by varying intensities of exercise such as: percentage of maximal heart rate (%HR$_{max}$), percentage of maximal oxygen uptake (% $\text{VO}_2_{max}$) and blood lactate. Initially, Borg had initially devised an oversimplified 21 point category-rating scale with verbal anchors arranged around a middle value of “neither light nor hard”, however this was deemed impractical for general exercise testing as the analogues scale/anchors did not ascend in linear relativity to variables such as HR and oxygen consumption (Borg, 2001:118). Hence, Borg developed the 15-point RPE scale ranging from 6 to 20 based on the physiological responses to exercise of a healthy middle-aged adult population performing incremental cycle ergometry where such ratings were selected to closely correspond to 1/10 of participants’ HR; for example an RPE of 17 would evoke an approximate HR of 170 beats per minute (bpm) (Borg, 2001). Recent literature has highlighted that an RPE of 14 corresponds to 80% of maximal heart rate (HRM) and thus detailing a feasible end point to that relationship (Buckley et al., 2004).
Of note, RPE is not influenced by fluctuations in HR, oxygen consumption and the accumulation of blood/muscle lactate which are in fact responses to the increased breathing/ventilatory work, muscle and joint strains, body temperature and general locomotion synonymous with increasing effort production (Buckley & Eston, 2007).

1.5.2 Use of RPE in Exercise Prescription

Low levels of cardiovascular fitness and physical activity as a result of sedentary lifestyles are synonymous with increased risk factors for numerous chronic disorders such as coronary artery disease, cardiovascular disease, hypertension, stroke, diabetes and some forms of cancer (Carmichael, 1999; Paffenbarger, 1986).

In order to prescribe exercise intensity it is often necessary to estimate a patient's maximal oxygen uptake (\( \dot{V}O_{2\text{max}} \)) capability (ACSM, 2006).

However, in a clinical setting it is not feasible to directly determine \( \dot{V}O_{2\text{max}} \) as this may jeopardise patient safety, therefore sub-maximal exercise testing is required to estimate \( \dot{V}O_{2\text{max}} \) (ACSM, 2006). Additionally, athletes are often unable to perform maximal tests close to competition due to the risk of injury or fatigue which could jeopardise their competitive performance (Dick, 2003; ACSM, 2006).

Contextually, RPE scales are commonly used as a response measurement during graded exercise due to their strong correlations with increments in both physiological (such as HR and \( O_2 \) uptake) and physical (such as speed and power output) markers of exercise intensity. This has lead to their role as a mode of passive estimation used to forecast future responses to incremental exercise demands
across a variety of populations (Eston et al., 2005). RPE scales are less commonly used in an active production mode, a logical application also devised to guide and regulate exercise intensity in both healthy and clinical populations (Eston et al., 2005).

Current literature surrounding the prescription of exercise recommends working within the perceptual RPE range of 12 to 16 to evoke a health positive physiological training effect (Whaley, Brubaker, Kaminsky & Miller, 1997b; ACSM, 2006; Winter, Jones, Davison, Bromley & Mercer, 2007).

RPE is therefore a desirable concept developed and expanded to provide simple markers by which to self-regulate exercise intensity, sustain adherence to exercise programmes, and allow health professionals to prescribe appropriate and safe exercise levels which promote health and fitness (Eston et al., 2005).

### 1.5.3 RPE Mode

The assumption made of RPE is that different perceptions of exertion closely correlate to predetermined levels of total body oxygen consumption which are stimulated by a broad spectrum of exercise intensities (Noble & Robertson, 1996). Therefore, RPE is often applied in the field of exercise prescription to assist in defining individualised training zones and regulate training intensity (Robertson, 2001).

When using RPE to prescribe exercise programmes for patients who are clinically impaired, such as those undertaking cardiopulmonary rehabilitation, an estimation-production paradigm is generally employed (Robertson, 2001). In order to prescribe
safe exercise RPEs must directly correspond to marked grades in a graded exercise test (GXT) so that prescribed intensities are equal to, but do not exceed those levels which have been deemed precarious by previous clinical studies (Robertson, 2001). Therefore, the GXT provides a highly practicable method of prescribing appropriate exercise intensities (Eston et al., 2005)

Estimation mode requires a participant to passively perform a GXT, often to maximal exertion, under a set protocol while assigning a number to a given exercise intensity (RPE) at set stages of the test; other physiological variables are also recorded simultaneously with RPE (such as HR and \( \dot{V}O_2 \)) (Robertson, 2001; Eston et al., 2005; Eston et al., 2006; Buckley & Eston, 2007; Eston, Lambrick, Sheppard & Parfitt, 2008; Faulkner, Parfitt & Eston, 2007).

On the other hand, production mode requires the participant to actively adjust their exercise intensity to conform to a given RPE, this can be done by manual control of the speed dials on a treadmill or by verbal instruction to the researcher while on the cycle ergometer (Dunbar et al., 1992; Robertson, 2001; Buckley & Eston, 2007). Physiological variables such as HR and \( \dot{V}O_2 \) values are recorded at each of the produced RPEs in order to compare regulatory responses, accuracy of perceptual judgements or to predict that participant’s \( \dot{V}O_{2\text{max}} \) (Robertson, 2001; Eston et al., 2005; Eston et al., 2006; Buckley & Eston, 2007; Eston et al., 2008; Faulkner et al., 2007).

Estimation-production protocols theoretically present an effective model of reciprocation as \( \dot{V}O_{2\text{max}} \) could be predicted by a sub-maximal production protocol
and confirmed by an estimation GXT procedure (Eston et al., 2005; Eston et al., 2006; Eston et al., 2008; Faulkner et al., 2007).

Reliability of an estimation-production protocol can be deemed if the physiological response to each given workload during the estimation mode mirrors the physiological and perceptual responses observed during the production bout (Eston et al., 2008).

However, Buckley and Eston (2007) warn that due to the active and passive nature of the respective production and estimation modes, comparisons between measurement variables for identical RPEs may not necessarily produce wholly accurate correlations.

RPE has most commonly been used as a response measurement in passive estimation exercise testing, whereas Eston et al. (2005) suggest that the lesser used active production mode is a highly logical application of RPE in regulating exercise intensity and determining appropriate ranges of exercise prescription for a given population.

1.5.4 Validity and Reliability of the RPE Scale of Regulating Exercise Intensity when Employed in an Estimation-Production Paradigm

Several studies have yielded favourable results advocating strong reliability and validity coefficients ($r = \geq 0.90$) when using RPE to complement heart rate as a physiological measure of determining levels of exertion in apparently healthy individuals, when maximum heart rate is calculated from the 220-age method (Borg, 1998; Borg, 2001).
Studies by Ceci and Hassmén (1991), Dunbar, Robertson, Baun, Blandin, Metz, Burdett and Goss (1992), Glass, Knowlton and Becque (1992), and Buckley, Eston and Sim (2000) have all found RPE to be physiologically valid method of regulating exercise intensity.

Ceci and Hassmén (1991) compared the outcome of running on a treadmill to that of outdoor running on a track using an RPE production protocol whilst assessing its efficacy over time (3-5 weeks). Healthy males (n=11; 42.9±11 years) were recruited to participate in two test sessions (1 treadmill session and 1 track session), performing identical running protocols to specified RPE anchors (11, 13, and 15 at 3, 11, and 5 minutes respectively) (Ceci & Hassmén, 1991). Test-retest reliability values of $r = 0.90$ or higher were achieved as velocity and heart rate were significantly different across the prescribed RPEs, whereas values yielded across trials at corresponding RPEs were similar, Ceci and Hassmén (1991) thereby advocating RPE as an effective tool of monitoring and regulating exercise intensity.

Dunbar et al. (1992) concur with Ceci and Hassmén (1991) as they further examined the efficacy of using an RPE production mode to assess the validity and repeatability of RPE. Using standard clinical protocols, participants were first instructed to produce and regulate their exercise intensity around specified and ascending RPEs, using both a treadmill and cycle ergometer; then on a separate occasion participants performed an estimation trial to compare corresponding physiological variables, predominantly HR (Dunbar et al., 1992). Participants exercised to RPE equivalents of 50% and 70% $\dot{V}O_2$max (RPEs 13 and 15 respectively), and thus the use of RPE was
validated as an effective means of regulating intra-and intermodal exercise at 50 and 70% of $\dot{V}O_{2\text{max}}$ on the cycle ergometer, however perceptual regulation of treadmill exercise at 70% was not wholly valid as recorded HR and oxygen consumption (O₂) values were found to be lower during production mode rather than estimation mode (Dunbar et al., 1992). The differences in accuracy highlighted between exercise modes implicate cycle ergometer exercise testing as a more precise mode when used in an estimation-production paradigm, perhaps due to the slow speeds and large inclines set within the treadmill protocols (namely the Bruce protocol) which may lead to uneven metabolic adaptations (Myers & Bellin, 2000; Eston et al., 2006). On the other hand, Dunbar, Goris, Michielli and Kalinski (1994) examined the accuracy of RPE in the regulation of exercise testing, and compared both treadmill and cycle ergometer exercise, they found that RPE guided treadmill exercise had the greatest validity. Untrained participants ($n=9$) were requested to perform two treadmill production trials and two cycle ergometer production trials whereby participants used their perceptions of effort to regulate the exercise intensity at an RPE equivalent to 60% of their $\dot{V}O_{2\text{max}}$ (Dunbar et al., 1994). It was found that RPE appears to be valid means of regulating exercise intensity when performing repeated bouts of treadmill exercise at 60% $\dot{V}O_{2\text{max}}$, however when considering cycle ergometry performed at that RPE (equating to 60% $\dot{V}O_{2\text{max}}$) % $\dot{V}O_{2\text{max}}$ may be lower than target as observed in the second cycle ergometer trial; a similar trend was also observed in HR across both cycle ergometer trials (Dunbar et al., 1994). Moreover, Glass et al. (1992) further investigated the reliability of employing an estimation-production paradigm to exercise testing and prescription based on the
perceptual responses of the participant body to the trial exercise implemented. Participants \((n=15\) males) initially performed a graded exercise test (GXT) on a motor driven treadmill, a GXT protocol is predetermined by the researchers and examines the variation of physiological responses to incremental exercise, whilst measuring variables such as HR, \(\dot{V}O_2\) and RPE at selected incremental stages (Glass et al., 1992). Following a 48 hour interval period (allowing for adequate rest, so to maintain test validity) participants were asked to return to the exercise laboratory and perform a ten minute exercise test (EXT) using the same treadmill, this occasion required participants to control the speed on the treadmill themselves in accordance to a set RPE as prescribed by the researchers (Glass et al., 1992). The RPE selected equated to 75\% of the heart rate reserve and RPE data as reported from the GXT, once again HR and \(\dot{V}O_2\) values were simultaneously recorded (Glass et al., 1992). Initially, it took several minutes during the EXT for participants to accurately find the range prescribed by the researchers (predicted in accordance with HR and \(\dot{V}O_2\) from the GXT) as significant mean differences \((p<0.05)\) were elicited from EXT heart rate in comparison to the GXT measurements \((154.9\pm4.5\) versus \(161.8\pm1.3\) bpm, respectively) (Glass et al., 1992). However, after a habituation-like period (by minute 6) participants were exercising to within four bpm of the target heart rate; no significant differences \((p>0.05)\) were found between GXT and EXT for \(\dot{V}O_2\) \((36.1\pm5.2\) and \(33.1\pm6.4)\) and ventilatory equivalent (\(\dot{VE}\)) \((64.1\pm10.8\) and \(58.4\pm13.5)\) respectively (Glass et al., 1992). From the data collected, Glass et al. (1992) concluded that the application of a GXT format to exercise testing can be employed to accurately prescribe exercise intensity during level treadmill running and it is especially advantageous as perceptually adjusted effort levels can be regulated whilst
exercising so the participant would not need to stop and self-record/measure HR during exercise.

Similarly, Buckley et al. (2000) proved Borg’s 6-20 RPE scale to be a valid and reliable tool in regulating cycle ergometry exercise in blind participants by using a Braille version of the scale, yielding similar effects as the analogues scale used for sighted people. Employing the estimation-production method, GXT cycle tests were performed by healthy, blind registered participants (n=10; four women, six men; age 23.2±9.0 years) to determine HR_{max} and VO_{2\text{max}} (Buckley et al., 2000). Participants were then required to perform three EXTs on separate days of the same week, working to their perceptions of RPEs 9, 11, and 13 (performed in a random order) whilst HR and VO_{2} were continuously recorded; each exercise bout (RPE 9, 11, and then 13) was followed by a 10 minute rest to ensure that values recorded at the next stage were not affected by short term fatigue (Buckley et al., 2000). A two factor (RPE x trial) repeated measures analysis of variance was performed to assess the validity of the RPE scale as a tool of producing different exercise intensities; additionally, intra-class correlation coefficients (ICC) and the bias ±95% limits of agreement (95%LoA) procedures were used to assess intertrial reliability (Buckley et al., 2000). At RPEs 9, 11, and 13 participants produced mean %VO_{2\text{max}} values of 47%, 53%, and 63% respectively, whilst analysis of variance displayed that between trials there were no significant differences found in either %HR_{max} or %VO_{2\text{max}} yet as expected significant results were found between the three RPE levels in both %HR_{max} and %VO_{2\text{max}} (p <0.001) (Buckley, et al., 2000). According to all pairwise comparisons of the three RPEs, each was significantly different (p <0.016) (Buckley et al., 2000). Moreover, the ICC performed between the second and third trial for %HR_{max
reported significance ($p < 0.05$) across all three RPEs; similarly, the ICC performed for
% $\bar{\dot{V}}O_{2\text{max}}$ displayed significant correlations for RPE 9 and 11 but not 13 (Buckley et
al., 2000). Notably, the 95%LoA decreased with each successive trial for both \%HR$_{\text{max}}$
and \% $\bar{\dot{V}}O_{2\text{max}}$ demonstrating progressive familiarisation with the production EXT
protocols (Buckley et al., 2000). Participants advocated the usability of the Braille
RPE scale using cycle ergometry, which also proved successful in its application as
adjuged by the intertrial reliability yielded from \%HR$_{\text{max}}$ and \% $\bar{\dot{V}}O_{2\text{max}}$ consistency
measures (Buckley et al., 2000).

Evidence thus far has found the estimation-production paradigm to produce positive
data highlighting that the Borg RPE scale provides an accurate means of regulating
exercise intensity around both visual, verbal and tactile anchors. Saliently, the
research procedures and protocols implemented by both Glass et al. (1992) and
Buckley et al (2000) required their participants to work at a \%HR$_{\text{max}}$ and \% $\bar{\dot{V}}O_{2\text{max}}$
levels which fall within the recommended range for developing cardiorespiratory
fitness, proving such protocol to be effective and successful in its aims.

However, recent research has flagged up inconsistencies regarding the reliability of
the RPE scale, particularly surrounding its efficacy within clinical settings, in respect
to the accuracy of specific anchors mirroring their predicted physiological
equivalents, such as HR or oxygen consumption (Whaley et al., 1997b; Lamb, Eston &
Corns, 1999).

Wenos, Wallace, Surburg and Morris (1996) questioned the test-retest reliability of
the RPE scale over a range of populations instead of the more typically enlisted
research participants. Therefore, Wenos et al. (1996) selected a sample group ($n=24$)
of elderly women (65±3.8 years) who were split into four test groups to perform either continuous or discontinuous exercise at intensities of 30, 50, and 70% of peak oxygen consumption (\(\dot{V}O_2\text{peak}\)). Wenos et al. (1996) unearthed findings opposing a universal reliability of RPE, reporting that reliability correlations at 30, 50, and 70% of \(\dot{V}O_2\text{peak}\) attained from the continuous walking protocol groups (\(r =0.53, 0.94,\) and 0.67 respectively) were less impressive than those calculated from the discontinuous walking protocol groups (\(r =0.96, 0.97,\) and 0.72 respectively). Wenos et al. (1996) therefore concluded exercise intensities prescribed for older women should be regulated around the perceptual marker corresponding to 50% \(\dot{V}O_2\text{peak}\), so to reach a reliable level of exertion.

However, Lamb, Eston and Corns (1999) concur with Wenos et al. (1996), questioning the validity of RPE in less active or exercise naive people due to S-R uncertainty.

Hence, in light of the work by Wenos et al. (1996), Lamb, Eston and Corns (1999) question traditionally employed techniques of statistical analysis suggesting that they provide an incomplete assessment of trends in repeatability. Lamb Eston and Corns (1999) highlight that such traditional indicators as Pearson Product-Moment correlation coefficients and ICCs merely base reliability judgements on the relative position of scores across the number of trials conducted (commonly two), such analysis focuses on determining whether the same participants recorded the same ranking across corresponding trials. Lamb, Eston and Corns (1999:336) therefore set out to examine the reliability of RPE during progressive treadmill exercise by employing a more recently advocated means of statistical assessment, the "95%
limits of agreement” technique, which instead bases reliability judgements on the size of the within-subjects (trial-to-trial) variability. Sixteen healthy male athletes were recruited (23.6±5.1 years) to perform two identical multistage (incremental) continuous treadmill running protocols over a period of five days, RPEs were reported at numerous stages of the exercise (Lamb, Eston & Corns, 1999). Findings questioned the test-retest reliability of Borg’s 6-20 RPE scale as the 95% limits of agreement (bias±1.96 x SD_{diff}) widened as exercise intensity increased: 0.88 (2.02), 0.25 (2.53), -0.13 (2.86) and -13 (2.94) RPE units were recorded at stages 1, 2, 3 and 4 respectively; in comparison Pearson correlations (0.81, 0.72, 0.65 and 0.60) and ICCs (0.82, 0.80, 0.77 and 0.75) elicited similar trends at corresponding RPE stages by decreasing as exercise intensity increased (Lamb, Eston & Corns, 1999).

Comparatively, Whaley et al. (1997b) conducted a large scale study to assess the validity of the generalised RPE recommendations by implementing sign-symptom limited maximal graded exercise test (GXT) in both a heterogeneous group of apparently healthy participants (n=463) and cardiac patients (n=217). RPEs associated with exercise intensities relative to 60 and 80% of maximal heart rate reserve (HRR_{max}) and peak exercise were selected as the parameters for analysis (Whaley et al., 1997b). Results coincided with the findings of Lamb, Eston and Corns (1999) as significant interindividual variability in RPE was observed across both populations at both relative exercise intensities (6 to 20 RPE range at 60% HRR_{max}; 8 to 20 range at 80% HRR_{max}) (Whaley et al., 1997b). Statistics displayed that 39% of healthy participants and 32% of cardiac patients reported an RPE outside the generally prescribed 11 to 14 range at 60% of HRR_{max}, similarly 32% of apparently healthy participants and 52% of cardiac patients reported an RPE outside of the
generally prescribed 14 to 17 range at 80% of HRR_{max} (Whaley et al., 1997b). Additionally, peak RPE recorded was higher for the apparently healthy participants as opposed to the cardiac patients (18.8±1.2 versus 16.5±1.8 respectively; \( p < 0.01 \)) (Whaley et al., 1997b). These findings further challenge the applicability of the generalised RPE recommendations outlined in the current exercise prescription literature when implemented within typical, clinical exercise testing settings and call for current guidelines to be revised (Whaley et al., 1997b).

Moreover, Whaley, Woodall, Kaminsky and Emmett (1997a) conducted a smaller study to test the reliability of RPE during graded exercise testing in apparently healthy adults by examining the perceptual-physiological relationship between two commonly used treadmill protocols, with results displaying a divergence in relationship between the two protocols as the exercise intensity increased over a range of 40-80% HRR_{max}. As a mixed gender participant group (n=38) performed the Balke and Bruce treadmill protocols, participants were asked to report their RPEs at corresponding time phases revealing significant protocol and gender differences (Whaley et al., 1997a). Participants adjudged RPEs significantly higher during the Balke protocol than the Bruce protocol at 40%, 60% and 80% of HRR_{max} (40% = 9.5±2.0 versus 8.3±1.6; 60% = 12.7±2.4 versus 11.1±2.3; 80% = 15.7±2.2 versus 14.1±2.0); in relation to gender differences, men matched significantly higher RPEs to each exercise intensity than the female participants (\( p < 0.05 \)) (Whaley et al., 1997a).

Additionally, Chen, Fan and Moe (2002) performed research to examine the validity of the Borg scale in light of the work by Wenos et al. (1996) Whaley et al. (1997a;
1997b) and Lamb, Eston and Corns, they analysed the relationship between RPE and numerous physiological criterion measures using mixed gender, mixed fitness level, different protocol and diverse exercise type studies. Chen, Fan and Moe (2002) therefore concluded that although figures of reliability and validity was not as tight as initially perceived, the results range revealed \( r = 0.80-0.90 \) shows that Borg’s RPE scale still stands up as a valid measure of exercise intensity.

Following an influx of research somewhat serving to discredit the validity and repeatability factors of the RPE scale, it would appear apposite to examine the efficacy of the RPE mediated estimation-production application when employed within a clinical setting.

As aforementioned, the estimation-production paradigm is commonly employed in exercise testing to determine safe and effective exercise intensities, modes and durations for cardio-selective and diabetic patients, both Eston and Connolly (1996) and Eston and Thompson (1997) have examined the efficacy of RPE when prescribing exercise for a designated clinical population.

Eston and Connolly (1996) specifically focused on the efficacy of RPE when it is used to prescribe exercise for patients receiving beta-blocker therapy, their rationale revolved around the original premise that RPE is strongly correlated with HR, yet beta-blocker therapy is proven to decrease HR (between 20-30%) and cardiac output at rest and during exercise, hence causing premature fatigue and exercise apprehension. Thus, Eston and Connolly (1996) propose that the RPE scale is an important tool when attempting to monitor and prescribe exercise intensity,
duration and mode as RPE response is mediated at a given work rate, this is particularly useful as different types of beta-blocker administered in a variety of dosages elicit different effects on cardiac output and thus the extent of HR suppression. Also, Eston and Connolly (1996) advise that non-selective beta-blocker therapy increases RPE, particularly localised RPE. Saliently, cardio-selective beta-blocker therapy reduces \( \dot{V}_O_{2\text{max}} \) thus increasing exercise intensity at all work rates, therefore RPE responses are higher than they would be in the absence of such therapy at similar intensity settings (Eston & Connolly, 1996). However, when a patient’s \( \dot{V}_O_{2\text{max}} \) has been determined, exercise intensities can be prescribed to them as a proportion of their attainable \( \dot{V}_O_{2\text{max}} \) causing the diversity in RPE responses to become minimised or disappear (Eston & Connolly, 1996). RPE is therefore advocated as an effective means of estimating exercise intensity as well as acting as a controlling variable in the regulation of the exercise response (Eston & Connolly, 1996). Notably, patients receiving beta-blocker treatment produce similar exercise intensities to other cardiac patients who are not receiving beta-blocker therapy; moreover, Eston and Connolly (1996) reference several studies which have shown endurance training to reduce RPE response to given exercise intensities over time in patients receiving beta-blocker therapy.

Eston and Thompson (1997) lead on by generating research which supports the notion of prescribing safe and effective exercise for patients receiving beta-blocker therapy by attempting to determine their \( \dot{V}_O_{2\text{max}} \) via RPE, and then working backwards to develop suitable and specific \( \dot{V}_O_2 \) to RPE ranges to promote positive health and exercise. Patients receiving atenolol (a type of beta-blocker prescribed for the treatment of essential hypertension) provided the focus of the study (Eston &
Thompson, 1997). A control group and a treatment group were set up; the control group consisted of 10 men and 10 women (aged 50±12 and 46±9 years respectively) who were not receiving beta-blocker therapy but did have risk factors for cardiovascular disease; opposite to the control group, the treatment group (11 men and 11 women; aged 53±13 and 55±13 years respectively were receiving regular dosages of between 25-100mg of atenolol (Eston & Thompson, 1997). Adopting an estimation-production method, all patients performed two sub-maximal exercise tests using a cycle ergometer (Eston & Thompson, 1997). The initial test involved each patient estimating an RPE to correspond to different levels of incremental exercise intensities, the second test required each patient to produce exercise intensities corresponding to predetermined anchors on the RPE scale (9, 13, 15, and 17), in accordance with their perception of those effort grades (Eston & Thompson, 1997). Findings confirmed a strong positive relationship between RPE and HR across both estimation and production protocols as work rate exhibited an individual correlation range in both tests of $r = 0.96$ to $r = 0.99$; no significant differences were found in $\text{HRR}_{\text{max}}$ and maximal power output in the control group from the linear regression predictions of either RPE versus maximal power output and RPE versus HR derived from the data collected from the estimation tests (Eston & Thompson, 1997). Yet, the prediction of maximal power output was significantly lower ($p < 0.01$) in the treatment group and in the women of the control group when predicted from the effort production protocol (Eston & Thompson, 1997). Most importantly there was no differences found between treatment and control groups when exercise intensity at each RPE was expressed relative to maximal power output, therefore advocating RPE as an effective predictor of maximal power output/ $\dot{V}\text{O}_{2\text{max}}$ when
used in an estimation-production paradigm (Eston & Thompson, 1997). However, Eston and Connolly (1997) urge caution when applying such procedures as predicted maximal exercise levels may be lower when employing an effort production mode.

1.5.5 The validity and reliability of prescribing safe and effective exercise by predicting maximal oxygen uptake (\( \dot{V}O_{2\text{max}} \)) from an RPE Production mode

Lamb et al. (1999) suggest that the major issue surrounding a genuinely valid role for the RPE scale in the prescription of exercise is the concerns over its reliability. In addition, Lamb et al (1999) state that a measurement technique cannot be deemed valid without proven reliability.

Studies such as that by Eston and Thompson (1997) have prompted further research into RPE centred exercise prescription where use of an alternative application of the estimation-production paradigm has been employed to validate new methods of predicting \( \dot{V}O_{2\text{max}} \), in order to provide safe and effective levels of exercise for hypertensive patients, those receiving cardio-selective beta-blocker therapy as well as diabetic individuals. Eston et al. (2005), Eston et al. (2006) and Eston et al. (2008) have successfully conducted studies achieving valid predictions of \( \dot{V}O_{2\text{max}} \) from sub-maximal, perceptually graded GXTs.

Eston et al. (2005) recruited ten male participants to perform firstly, a continuous GXT to maximal exertion so to determine \( \dot{V}O_{2\text{max}} \), following this participants performed three discontinuous/intermittent sub-maximal RPE production protocols, perceptually self-regulating workload to the ascending intensities of 9, 11, 13, 15, and 17 on the RPE scale. All testing was performed on a cycle ergometer and was
completed over an 8 day period (a break of 48hrs was allotted between individual trials) (Eston et al., 2005). Participants were given 2-3 minutes to adjust to each prescribed RPE and continued to cycle to that specific intensity for a further four minutes while levels of expired air were recorded continuously, following this participants continued to cycle at a low intensity for four minutes (recovery period to enhance reliability) thus allowing their breathing rate to return to normal before performing the identical procedure at the next specified RPE (Eston et al., 2005). Fletcher, et al. (2001) state that Eston et al. (2005) provided their participants with a more than adequate timeframe to collect accurate O₂ uptake and expiration levels as oxygen uptake increases sharply when dynamic exercise is begun or increased, and therefore during graded exercise testing O₂ uptake usually remains relatively stable (steady state) after the second minute of each new intensity of exercise when below the ventilatory threshold. Eston et al. (2005) therefore hypothesised that a strong relationship between RPE and O₂ uptake would be prominent allowing them to successfully predict \( \dot{V}_\text{O}_2\text{max} \) with acceptable accuracy, such accuracy would improve and progress throughout the three trials due to familiarisation and habituation as Lamb et al. (1999) and Eston et al. (2006) would concur. Across the three production trials, participants' RPE values revealed correlations in the range \( r = 0.92-0.99 \) (Eston et al., 2005). Saliently, there were no significant differences between predicted \( \dot{V}_\text{O}_2\text{max} \) values (47.3, 48.6 and 49.9 ml·kg\(^{-1}\)·min\(^{-1}\), for trials 1, 2, and 3 respectively) and the measured \( \dot{V}_\text{O}_2\text{max} \) (48.8 ml·kg\(^{-1}\)·min\(^{-1}\)), when \( \dot{V}_\text{O}_2\text{max} \) was predicted from the RPE value range of 9-17, and also when predicted from the RPE value range 9-15 (Eston et al., 2005). Following LoA analysis on actual and predicted \( \dot{V}_\text{O}_2\text{max} \) values from RPE range 9-17 for trials 1, 2, and 3 were \( 1.5 \pm 7.3, 0.2 \pm 4.9, \) and \( -1.2 \pm 5.8 \text{ ml·kg}^{-1} \text{·min}^{-1} \).
1-min\(^{-1}\) (bias±1.96xSDdiff), respectively (Eston et al., 2005). Additionally, corresponding LoA values for actual and predicted \(\dot{V}O_{2max}\) from RPE range 9-15 were 5.4±11.3, 4.4±8.7 and 2.3±8.4 ml·kg\(^{-1}\)·min\(^{-1}\), respectively (Eston et al., 2005). Such findings lead Eston et al. (2005) to conclude that sub-maximal, perceptually-guided, graded exercise protocol can provide acceptable estimates of \(\dot{V}O_{2max}\). Thus far, this study only proves that such a test protocol is acceptable and successful in fit young males and therefore further study into areas such as gender, age and health status is required. However, such a strict and rigorous procedure was employed throughout the study ensuring reliability and validity; test parameters such as enforcing a 48 hour gap between testing sessions, implementing recovery periods between RPE levels during cycle ergometry and the use of three trials per person add powerful support to current practice as well as endorse future investigation.

Eston et al. (2006) therefore expanded on the work by Eston et al. (2005) by conducting a further study to assess the validity and reliability of predicting \(\dot{V}O_{2max}\) from RPE regulated exercise tests, by involving a number of additional test variables and altering protocol parameters. The first obvious difference in this study is the inclusion of a female participant body (n=9; 21.4±1.4 years) as well as a male component (n=10; 21.6±0.8 years), participants were all classed as physically active (Eston et al., 2006). Each participant was required to perform four continuous and incremental, perceptually regulated EXTs (exercising to the through the chronological RPE range of 9, 11, 13, 15, and 17) to predict \(\dot{V}O_{2max}\) over a 2-week period (Eston et al., 2006). Additionally, participants were required to perform a GXT to volitional exhaustion prior to the EXTs and another preceding the EXTs to determine actual \(\dot{V}O_{2max}\) (Eston et al., 2006). All GXT and EXT testing was performed
on a cycle ergometer, two of the four exercise bouts required participants to
eexercise at each specified RPE for a duration of two minutes, whereas participants
were required to exercise at each designated RPE for a duration of four minutes in
the remaining two exercise bouts (2x2min; 2x4min) (Eston et al., 2006). Using the
LoA technique, linear relationships between RPE and $\dot{V}_O_{2\text{max}}$ were assessed for RPE
ranges 9-17, 11-17, and 9-15 as they extrapolated to RPE 20 to predict $\dot{V}_O_{2\text{max}}$ (Eston
et al., 2006). Estimated $\dot{V}_O_{2\text{max}}$ when using RPE 9-17 from trial 1 of the 2-min
protocol was found to be significantly lower ($p <0.05$) than $\dot{V}_O_{2\text{maxGXT}}$ ($\dot{V}_O_{2\text{max}}$ as
determined by GXT) as well as the $\dot{V}_O_{2\text{max}}$ predicted from both 4-min trials (Eston et
al., 2006); Fletcher et al. (2001) would attribute this finding to the inability of $O_2$
uptake to reach a steady state in a short timescale. However, relationships between
RPE and $\dot{V}_O_{2\text{max}}$ from trial 2 of the 2-min protocol revealed strong correlations to
both predicted $\dot{V}_O_{2\text{max}}$ values and actual $\dot{V}_O_{2\text{maxGXT}}$ values, these findings also
proved to be a more accurate prediction of $\dot{V}_O_{2\text{maxGXT}}$ across all trials; this outcome
could be explained by a learning effect evoked in the participants, a familiarisation
where the participant grows more accustomed to accurately interpreting their
feelings of exertion over time with practice (Eston et al., 2005; Eston et al., 2006).
Furthermore, Noakes (2004) refers to the notion that participant awareness of
exercise duration and pending increments in power output may elicit a subconscious
effect on effort. To elaborate, as participants were fully appraised of the duration of
each trial as well as the incremental stages of intensity, they may make subliminal
judgements or decisions on how long they desire to concentrate accurately on
producing a specific high order RPE, thus causing attentional drift, or participants
may even adopt pacing strategies to conserve energy for the forthcoming RPE stage;
thus, a 4-min trial may lead to marginally lower $\dot{V}_{O_{2\text{max}}}$ estimations than actual $\dot{V}_{O_{2\text{max}}}$ values recorded (Hampson, Gibson, Lambert & Noakes, 2001; Noakes, 2004; St Clair Gibson., 2006). Additionally, if a participant finds the exercise tedious or painful/uncomfortable for longer than they feel they can tolerate then the accuracy of data collected may be compromised due to a scenario of under estimation (Parfitt, Eston & Connolly, 1996). However, it was found that the intraclass coefficient was higher between $\dot{V}_{O_{2\text{max}GXT}}$ and $\dot{V}_{O_{2\text{max}}}$ predicted from trial 2 of the 2-min protocol compared to both trials of the 4-min protocols as $r = 0.95$, 0.88, and 0.79 respectively; similar results were observed for RPE ranges 9-15 and 11-17, reporting $r = 0.89$, 0.78, 0.84 and $r = 0.94$, 0.76, and 0.82 for the respective RPE ranges (Eston et al., 2006). Lastly, it is of great interest that Eston et al. (2006) were able to report no significant gender differences between actual $\dot{V}_{O_{2\text{max}}}$ values measured from a graded exercise test (GXT) to volitional exhaustion and the $\dot{V}_{O_{2\text{max}}}$ values predicted from sub-maximal, perceptually-guided EXTs (self-regulated at RPEs 9, 11 13, 15 and 17) when using a cycle ergometer as the exercise mode (by method, $p =0.630$; by trial, $p =0.786$). Faulkner et al. (2007) concur with Eston et al. (2006) as they observed no significant gender effect on $\dot{V}_{O_{2\text{max}}}$ predictions ($p >0.005$).

Buckley et al. (2004) provide data which further supports the robustness of the findings by both Eston et al. (2005) and Eston et al. (2006), quantifying the validity of a popular step test (the Chester Step Test) against a treadmill protocol. Using a similar university sample population in respect to age, gender and $\dot{V}_{O_{2\text{max}}}$ to that of the participants recruited in the study by Eston et al. (2006), the 95% LoA for predicted $\dot{V}_{O_{2\text{max}}}$ values were calculated as $-2.8\pm6.1$ and $-1.9\pm7.4$ ml·kg$^{-1}$·min$^{-1}$ for
trials 1 and 2 respectively; trial 2 provided the best LoA meaning that in the worst case scenario the range by which a predicted $\dot{V}O_2_{\text{max}}$ might occur could be 5.5 ml·kg$^{-1}$·min$^{-1}$ above or 9.3 ml·kg$^{-1}$·min$^{-1}$ below actual $\dot{V}O_2_{\text{max}}$ values (Buckley et al., 2004; Eston et al., 2005). In comparison, the LoA analysis conducted by Eston et al. (2006) highlights more favourable estimates in the eventuality of a worst case scenario, indicating a range of 5.1 ml·kg$^{-1}$·min$^{-1}$ above and 4.7 ml·kg$^{-1}$·min$^{-1}$ below actual $\dot{V}O_2_{\text{max}}$ values recorded. Moreover, Eston et al. (2006) outline that the 9-17 RPE intensity range revealed the highest ICC values and 95% LoA when predicting $\dot{V}O_2_{\text{max}}$ from RPE in comparison to 9-15 and 9-17 RPE ranges which were also extrapolated; predicted $\dot{V}O_2_{\text{max}}$ ranges yielded were ±7.4 ml·kg$^{-1}$·min$^{-1}$, ±10.6 ml·kg$^{-1}$·min$^{-1}$, and ±8.5 ml·kg$^{-1}$·min$^{-1}$, respectively. Predictions of $\dot{V}O_2_{\text{max}}$ accrued and their accuracy to actual $\dot{V}O_2_{\text{max}}$ values vary across the studies carried out by Buckley et al. (2004), Eston et al. (2005) and Eston et al. (2006), yet all findings carry statistical weighting and outline repeatability and validity factors within RPE and estimation-production orientated research.

The studies performed by Eston et al. (2005) and Eston et al. (2006) have prompted further investigation from Eston et al. (2008) who observed that the sample populations examined in the aforementioned studies recruited young, fit, and active men and women, thus leading them to consider how accurately such estimation-production procedural measures could predict $\dot{V}O_2_{\text{max}}$ in a sedentary population. Eston et al. (2008) applied the theory that active individuals have a greater tolerance to high-intensity exercise than do their less active counterparts and so conducted a similar study to that of Eston et al. (2005). In a single gender study thirteen
sedentary males (aged between 29-52 years; mean age 38.4 years) were recruited from a university staff population to perform five GXTs on a cycle ergometer over a ten day period (Eston et al., 2008). The first and final tests involved a GXT test to maximal exertion to ascertain actual \( \dot{V}\text{O}_{2\text{max}} \) values, the three tests in the middle were sub-maximal perceptually regulated graded exercise tests were each of the RPE intensities 9, 11, 13, 15, and 17 were performed chronologically for 3-min in a continuous fashion (Eston et al., 2008). Results displayed that acceptable estimates of \( \dot{V}\text{O}_{2\text{max}} \) can be achieved by sub-maximal, perceptually guided GXTs in young to middle-aged sedentary men (Eston et al., 2008). For the benefit of analysis, RPE was observed to provide narrowly more accurate predictions of \( \dot{V}\text{O}_{2\text{max}} \) than HR \( (r^2 =0.85 - 1.00 \text{ versus } r^2 =0.83 - 1.00, \text{ respectively}) \) (Eston et al., 2008). Once regression equations were performed for the RPE ranges 9-17, 9-15, and 11-17 and then extrapolated to RPE 20 to predict \( \dot{V}\text{O}_{2\text{max}} \) it was found that there were no significant difference between the actual \( \dot{V}\text{O}_{2\text{max}} \) values (mean 43.9±6.3 ml·kg\(^{-1}\)·min\(^{-1}\)) and predicted \( \dot{V}\text{O}_{2\text{max}} \) values for the RPE ranges 9-17 (40.7±2.2 ml·kg\(^{-1}\)·min\(^{-1}\); \( p =0.124 \)) or indeed the perceptual ranges 11-17 (42.5±2.3 ml·kg\(^{-1}\)·min\(^{-1}\); \( p =0.556 \)) (Eston et al., 2008). However, predicted \( \dot{V}\text{O}_{2\text{max}} \) values from the RPE range 9-15 were found to be significantly lower (37.7±2.3 ml·kg\(^{-1}\)·min\(^{-1}\); \( p =0.001 \)) (Eston et al., 2008). According to Lamb (1996) and Carter, Jones, Barstow, Burnley, Williams and Doust (2000), greater sensations of local effort are experienced at the higher RPE levels, therefore sensational magnitude and perceptual rigour are not as sharp around the lower RPE order, thus accounting for the significantly lower predictions of \( \dot{V}\text{O}_{2\text{max}} \) at the RPE range of 9-15. Strong ICCs were found between actual and predicted \( \dot{V}\text{O}_{2\text{max}} \) for RPE 9-17 and RPE 11-17 across the three trials \( (r =0.80 \text{ to } 0.87) \); values for RPE range 9-15
also reported high correlation coefficients across the three trials (0.86, 0.81, and 0.72 for trials 1, 2, and 3 respectively), illustrating that their range values were not too short of acceptable accuracy (Eston et al., 2008). Impressively, LoA analysis on actual $\dot{V}O_{2\text{max}}$ values and those predicted from the RPE production range of 9-17 reported acceptable estimates of $3.4\pm 10.7$ ml·kg$^{-1}$·min$^{-1}$, $2.4\pm 9.9$ ml·kg$^{-1}$·min$^{-1}$, and $3.7\pm 12.8$ ml·kg$^{-1}$·min$^{-1}$ across trials 1, 2, and 3 respectively (Eston et al., 2008). Such research provides sound evidence that the application of RPE in this manner holds credible accuracy when implemented across a broad population base.

Faulkner et al. (2007) offer further evidence backing up the findings of Eston et al. (2008) by following the same line of methodical investigation. Faulkner et al. (2007) examined the efficacy of applying such RPE estimation-production procedures both active and sedentary participants. Participant recruitment amassed thirteen physically active males (30.7±8.1 years), nine physically active females (31.9±12.3 years), fourteen sedentary males (28.1±7.6 years), and nine sedentary females (34.8±11.0 years) to perform two GXT continuous and incremental $\dot{V}O_{2\text{max}}$ tests, one either side of three sub-maximal exercise production tests at RPEs 9, 11, 13, 15, and 17 (Faulkner et al., 2007). Following LoA regression through the RPE ranges 9-17, 9-15, and 9-13, calculations were subsequently extrapolated to both RPE 19 and 20; as hypothesised $\dot{V}O_{2\text{max}}$ predictions reflected no significant differences to actual $\dot{V}O_{2\text{max}}$ values across all RPE regression ranges including 9-15, this presents a contrast to the data produced by Eston et al. (2008). The extrapolation of $\dot{V}O_{2}$ to RPE 19 from all three trials yielded no significant values in comparison to actual $\dot{V}O_{2\text{max}}$ values (40.8±10.4 42.0±11.1 42.4±10.7 ml·kg$^{-1}$·min$^{-1}$ for trials 1, 2, and 3 respectively,
compared to the actual mean $\dot{V}O_{2\text{max}}$ of 42.7±10.6 ml·kg$^{-1}$·min$^{-1}$). Faulkner et al. (2007) go on to suggest that perceptually-regulated production protocols corresponding to RPE values 13 or 15 may have significant potential for predicting $\dot{V}O_{2\text{max}}$ in healthy sedentary men and women. Faulkner et al. (2007) also reported that the prediction of $\dot{V}O_{2\text{max}}$ was not moderated by activity status.

Although LoA analyses conducted in the studies by Buckley et al. (2004), Eston et al. (2006) and Eston et al. (2008) provide acceptable estimates of maximal aerobic power, accuracy may be improved further by extrapolating the production RPE range (for example 9-15) by the maximal RPE achieved and reported by a participant in their GXT to volitional exhaustion (either 19 or 20), instead of repeatedly using RPE20 as employed by Eston et al. (2006). As BASES (1997) outline, volitional exhaustion can be achieved at RPE 19 or RPE 20; although RPE 20 is the highest RPE that can be reported on the scale participants are not necessarily likely to perceive that they have exercised to ‘maximal exertion’. To highlight this possible limitation to prediction/actual $\dot{V}O_{2\text{max}}$ accuracy, Faulkner et al. (2007) found that when extrapolating the RPE 9-17 to RPE20 $\dot{V}O_{2\text{max}}$ predictions were significantly overestimated ($p <0.05$).

Buckley et al. (2004) speculate that the reliability of predicting $\dot{V}O_{2\text{max}}$ using RPE progressively increases when exercise is produced to an intensity (RPE level) ≥50% of an individual’s $\dot{V}O_{2\text{max}}$. The findings presented by Buckley et al. (2004) therefore advocate working participants to an RPE of 14.2±2.0 (which equates to a mean % $\dot{V}O_{2\text{max}}$ of 65.6±10.4) and above, they suggest that this is due to sensations of exertion becoming stronger and more apparent to the participant. Marriott and
Lamb (1996) concur as they examined the use of RPEs for regulating exercise levels in rowing ergometry. They found significant differences \( (p < 0.05) \) in mean HR recorded at the two lowest RPE levels prescribed (11 and 13) when compared from one estimation trial and one production trial in nine competitive male rowers (aged 28.6±6.3 years) (Marriott & Lamb, 1996). There were no significant differences found in mean HR across both trials at RPEs 15, 17, and 19 (Marriott & Lamb, 1996). However, the estimation trial progressed in an incrementally chronological RPE order whereas the production trial progressed in the RPE order of 15, 11, 17, 13, and 19, therefore the lowest RPEs preceded higher order RPEs and thus consecutively disturbed an ascending HR rhythm (Marriott & Lamb, 1996).

Further inconsistencies have been found by Dunbar et al. (1992; aforementioned in section 1.6.4, page 14) and Kang, Chaloupka, Mastrangelo, Donnelly, Martz and Robertson (1998) who have reported that exercise intensity appears to be lower in production mode than estimation mode when comparing the physiological variables from corresponding RPEs. Kang et al. (1998) examined the validity of using PE to regulate exercise in both the upper and lower extremities by recruiting participants to perform arm and leg ergometry. Participants (ten men and seven women; aged 26±1 years) were required to complete a GXT estimation trial where they would report RPE at each grade, and then participants would perform two sub-maximal production trials on both an arm and a leg ergometer, exercising to 50% and 70% of peak oxygen consumption \( (\dot{V}O_2\text{peak}) \) (Kang et al., 1998). When performing the production trials, participants were instructed to achieve exercise intensities matching the RPEs they reported during the maximal estimation trial (Kang et al., 1998). Findings displayed that there were no differences in \( \dot{V}O_2 \) between arm
ergometry trials at 50% or 70% $\dot{V}O_2$peak, nor were any differences reported in leg $\dot{V}O_2$ at 50% of $\dot{V}O_2$peak (Kang et al., 1998). However, leg ergometry at 70% $\dot{V}O_2$peak was significantly different ($p < 0.05$) between estimation and production trials ($2.08\pm0.14$ ml·kg$^{-1}$·min$^{-1}$ versus $1.88\pm0.15$ ml·kg$^{-1}$·min$^{-1}$, respectively), thus depicting that exercise intensity is perceived as lower in production mode as opposed to estimation mode (Kang et al., 1998). Such a discrepancy may be attributed to the inability of a participant to accurately judge comparatively similar physiological responses between passive and active processes, thus affecting a perceptual underproduction (Eston et al., 2005).

In review of the studies provided by Eston et al. (2005) and Eston et al. (2006) and the discussed critique of their methods and results, it would appear as though continuous production protocol is efficacious as is a minimum of two to three production trials where each RPE stage lasts for no less than two minutes and ideally less than four minutes; and notably such research would appear not to be moderated by gender.

### 1.5.6 Exercise Mode

The reliability of the RPE scale has been predominantly assessed by either the motorised treadmill or cycle ergometry, however it has also been examined by rowing ergometry (Marriott & Lamb, 1996), walking (Wenos et al., 1996), stepping (Walker, Lamb & Marriott, 1996; Buckley et al., 2004), wheelchair exercise (Ward, Bar-Or & Longmuir, 1996), running (Ceci & Hassmén, 1991), swimming (Ueda & Kurokawa, 1995) and by way of a Nordic Track cross-country ski-simulator (Haug,
Porcari, Brice & Terry, 1999), arm ergometry (Kang et al., 1998) all with reporting acceptable reliability.

The validity of differentiated testing methods is often questioned as different modalities place emphasis on either peripheral or central mechanisms, such as the concentration on the lower extremities in cycling ergometry in comparison to whole-body movements involved in treadmill running (Green, Crews, Bosak & Peveler, 2002; Jondeau et al., 1992). Therefore, different exercise modalities will recruit different percentages of skeletal muscle mass, this may potentially affect the validity of any accrued $\dot{V}O_2$ values recorded at a given RPE (Bassett & Howley, 2000; Jondeau et al., 1992). Thus, the chosen mode of exercise is likely to influence effort perception as a local exertion may appear more prominent to the participant than a whole-body modality.

In a study by Lamb (1996), 29 untrained male participants performed $\dot{V}O_{2\text{max}}$ protocols on both a treadmill and a cycle ergometer, during each test protocol HR, $\dot{V}O_2$ and RPE (overall, peripheral and central/respiratory) measurements were recorded at intensities in line with blood lactate levels corresponding to different percentages within the lactate threshold and at maximal exercise. Lamb (1996) found that despite differences in HR and $\dot{V}O_2$ across treadmill exercise and cycle ergometry at corresponding blood lactate levels, RPE was not significantly different, implicating lactate as a physiological mediator in the perception of exertion during exercise. Such findings would support the notion that a given RPE may yield conflicting $\dot{V}O_2$ values across a range of exercise modalities. Furthermore, Lamb (1996) reported that peripheral RPE was greater than central/respiratory RPE in
cycle exercise and would appear to comprise a greater percentage of the overall perception of effort.

Moreover, Ekblom and Goldberg (1971) produced early data which would agree with the trends found by (Lamb (1996), reporting that O₂ consumption and HR at a given RPE were higher in cycle exercise as opposed to treadmill running. Carter et al. (2000) concur, providing evidence to further support the notion that RPE is highly exercise mode specific. Carter et al. (2000) compared the oxygen kinetics of seven recreationally active participants (three men, four women; aged 27±5 years) via \( \dot{V}O_{2\text{max}} \) testing using both a cycle ergometer and a treadmill. Treadmill running yielded significantly higher \( p<0.05 \) \( \dot{V}O_{2\text{max}} \) scores than cycle ergometry (50.7±13 ml·kg\(^{-1}\)·min\(^{-1}\) versus 43.1±11 ml·kg\(^{-1}\)·min\(^{-1}\), respectively) (Carter et al., 2000). It has therefore been speculated that differences in \( \dot{V}O_{2} \) values between exercise modes are related to the higher intramuscular tension developed in heavy cycle exercise and the higher eccentric exercise component in running (Carter et al., 2000:899). They go on to suggest that this may cause a relatively greater recruitment of the less efficient type II muscle fibres in cycling exercise (Carter et al., 2000:899).

Moreover, Dunbar et al. (1992) compared the validity and reliability the RPE scale in both treadmill running and cycle ergometry (study is outlined on page 14, section 1.6.4), and established greater test-retest reliability from the cycle exercise as opposed to the treadmill running. However, a number of explanations have been proposed for this finding, firstly Carter et al. (2000) would concur with Lamb (1996) stating that an emphasis on local muscle fatigue may heighten sensory awareness and thus providing a more accurate perceptual interpretation of an acute peripheral
signal. It is further suggested that as cycle ergometry is supported by a seat then the participants’ attention is not averted by having to maintain balance as they would when running on a treadmill belt (Dunbar et al, 1992). Dunbar et al. (1992) go on to add that discrepancies in reported \( \dot{V}O_2 \) values between the two exercise modalities when employing a production protocol could be attributed to the additional task placed on the participant of having to manually regulate their speed. The introduction of an additional cue may further influence participant perceptions of exertion by heightening their awareness of speed and possibly causing distractions from actual sensations (Dunbar et al., 1992).

Contrastingly, Dunbar et al (1994) report confounding data to that presented by Dunbar et al. (1992). Dunbar et al. (1994) examined the accuracy of regulating exercise by RPE and found treadmill exercise to achieve a greater level of validity to that of cycle ergometry. Participants were instructed to use their perceptions of effort to regulate exercise intensity at an RPE equivalent to 60% of their \( \dot{V}O_{2\text{max}} \), however cycle exercise consistently recorded \( \dot{V}O_{2\text{max}} \) and HR below the target values (Dunbar et al., 1994). These findings contradict the notion that a peripheral effort in cycling is more obvious to the perceptions of the participant than whole-body sensations in treadmill exercise. However, such inaccuracies could be attributed to lower sensations of exertion and thus lower perceptions of exertion at the lower intensities (Lamb, 1996; Marriott & Lamb, 1996; Buckley et al., 2004; Eston et al., 2008).

The differences in accuracy highlighted between exercise modes tend to implicate cycle ergometer exercise testing as a more precise mode when used in an
estimation-production paradigm, perhaps due to the slow speeds and large inclines set within the treadmill protocols (namely the Bruce protocol). Myers and Bellin (2000) elaborate, stating the reason for this inconsistent trend is that protocols employing large and/or unequal increments in work can disrupt linearity between \( \dot{V}O_2 \) and work rate, and thus lead to an over-prediction of metabolic equivalents. Such a limitation draws parallels with the protocol selection employed by Lamb, Eston and Corns (1999) whose research questioned the reliability (repeatability) of RPE during progressive incremental treadmill exercise, their protocol adopting an emphasis on gradient whilst maintaining a constant speed. Yet, Lamb, Eston and Corns (1999) highlight limitations within their own study which are relevant to prior research such as the work of Dunbar et al. (1992), limitations which are echoed by Eston et al. (2006) and offer support to such treadmill protocols as the Bruce protocol which places emphasis on gradient above speed; these academics express that studies assessing RPE reliability are hindered by performing limited trials (2 or less) as the initial test is predominantly a familiarisation exercise, for example the treadmill requires focus and effort to attain and maintain balance as well as adjusting to exercise if necessary, exercise mode and gas analysis equipment if used (such as the wearing of a face mask); therefore, in order to achieve a good level of between-trial reliability when assessing the effectiveness of RPE scales on different exercise modes and using different criterion groups, two or more production trials per participant is necessary to offset variability caused by uncertainty and adaptation in exercise naive people.

To this end it should be proposed that the validity and reliability of predicting \( \dot{V}O_{2\text{max}} \) from RPE regulated treadmill exercise requires examination.