



Sport and Health Sciences, College of Life and Environmental Sciences,
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Perceived Exertion Relationships and Prediction of Peak Oxygen Uptake in Able-bodied and Paraplegic Individuals

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Harran AlRahamneh

Abstract

Abstract

Rating of Perceived Exertion (RPE) relates to how 'hard' or 'easy' an exercise feels. The Borg 6-20 RPE scale is the most widely used scale to estimate the overall, peripheral and central perception of effort. To date, there are a limited number of studies on the use and efficacy of perceived exertion in persons with spinal cord injury and/or disease. The findings from these studies are also equivocal. Therefore, the aims of this thesis were to assess: i) the relationship between the RPE and physical and physiological markers of exercise intensity during arm cranking exercise in able-bodied and individuals with spinal cord disease, ii) the efficacy of sub-maximal RPE values to predict peak oxygen uptake during arm cranking exercise in able-bodied and paraplegic individuals using different exercise protocols, iii) the scalar property of the RPE during arm cranking exercise in able-bodied and paraplegic individuals. To achieve these goals, the thesis has been broken down to a series of seven studies. In each of these studies, except study 6, a group of able-bodied and a group of paraplegic participants were recruited to asses these hypotheses. Paraplegic individuals had spinal cord injury with neurological levels at or below the sixth thoracic vertebra (T6) or flaccid paralysis as a result of poliomyelitis infection. These individuals were physically active and participated in sports like wheelchair basketball, weightlifting, wheelchair racing and table tennis at both professional and recreational levels. Able-bodied participants were healthy and free from pre-existing injuries and physically active but not arm-trained.

There were strong relationships between the RPE and each of the physiological and physical indices of exercise intensity during arm cranking exercise regardless of group or gender. Peak oxygen uptake can be predicted with reasonable accuracy from sub-maximal oxygen uptake values elicited during a sub-maximal perceptually-guided, graded exercise test for paraplegic individuals but not for able-bodied participants. It has also been shown that peak oxygen uptake can be predicted from power output using the equation prescribed by the American College of Sports Medicine (ACSM, 2006). Furthermore, for able-bodied participants using *estimation* procedures, a

Abstract

passive process in which an individual is asked to rate how ‘hard’ or ‘easy’ an exercise feels, the ramp exercise test provided more accurate prediction of peak oxygen uptake compared to the graded exercise test. For paraplegic persons using *estimation* procedures, the graded exercise test provided more accurate prediction of peak oxygen uptake compared to the ramp exercise test. Finally, the scalar property of the RPE (i.e., similar proportions of time at a given RPE) was evident during arm cranking exercise regardless of group.

In conclusion, the prediction of peak oxygen uptake from sub-maximal exercise tests would provide a safer environment of exercise testing. In addition, using a sub-maximal protocol would make peak oxygen uptake more available for sedentary and clinical population compared to the graded exercise test to volitional exhaustion. Prediction of peak oxygen uptake from power output using the ACSM equation would make the estimation of peak oxygen uptake more available for large groups of people. Similar proportions of time were observed at a given RPE regardless of group or exercise intensity. The early RPE responses will give an indicator for how long a participant is going to exercise. This has important implications for rehabilitation settings. Based on the RPE responses the tester or the observer can increase or decrease the work rate to enable the participant to exercise for the desired duration.

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List of abbreviations

ACSM - American College of Sports Medicine

BACR - British Association of Cardiac Rehabilitation

BASES- British Association of Sport and Exercise Sciences

$\dot{V}O_2$ - Volume of Oxygen Uptake

$\dot{V}O_{2\max}$ - Volume of Maximal of Oxygen Uptake

$\dot{V}O_{2\text{peak}}$ - Volume of Peak Oxygen Uptake

$\dot{V}CO_2$ - Carbon Dioxide

RER - Respiratory Exchange Ratio

\dot{V}_E - Volume of expired air per minute (Ventilation)

$\dot{V}_{E\max}$ - Maximal Expired Air per Minute (Ventilation)

HR - Heart Rate

HRmax - Maximal Heart Rate

$\dot{V}_E/\dot{V}O_2$ - Ventilatory Equivalent for Oxygen

$\dot{V}_E/\dot{V}CO_2$ - Ventilatory Equivalent for Carbon Dioxide

RPE - Rating of Perceived Exertion

RPEo - Overall Rating of Perceived Exertion

RPEp - Peripheral Rating of Perceived Exertion

PO - Power Output

POmax - Maximal Power Output

POpeak - Peak Power Output

W - watt

rpm - Revolutions per Minute

SCI - Spinal Cord Injury

SCD - Spinal Cord Disease

ANOVA - Analysis of Variance

ANCOVA - Analysis of Covariance

LoA - Limits of Agreement

List of abbreviations

ICC - Intraclass Correlation Coefficients

SD - Standard Deviation

GXT - Graded Exercise Test

GET - Gas Exchange Threshold

HRR - Heart Rate Reserve

$\dot{V}O_2R$ - Oxygen Uptake Reserve

CNS - Central Nervous System

PNS - Peripheral Nervous System

SNS - Somatic Nervous System

ANS - Autonomic Nervous System

Polio - Poliomyelitis

s - second

min - minute

T - Thoracic vertebra

L - Lumbar vertebra

C - Cervical

S - Sacral

SPSS - Statistical Package for Social Sciences

Chapter 1

Introduction

Perceived exertion refers to how we discern and interpret our feelings arising from the body during exercise (Noble and Robertson, 1996). It is an active and continuous process in our daily life activities. In other words, all of us perceive these activities and adjust our pace (e.g., slow down or speed up) upon these feelings (Noble and Robertson, 1996). The afferent-feedback from the cardiovascular and respiratory systems, metabolic and thermal stimuli and the efferent feed-forward mechanisms constitute the basis which allows the person to appraise how ‘hard’ or ‘easy’ an exercise feels (Eston, 2009b). Interest in the area of perceived exertion during exercise started in the late 1950s and early 1960s (Borg and Dahlström, 1960). In 1970, the Borg 6-20 Ratings of Perceived Exertion (RPE) Scale, the most popular rating of perceived exertion scale, was developed and published (Borg, 1970). The importance of this area stems from the need for a subjective criterion to complement the objective measures such as heart rate (HR), oxygen uptake ($\dot{V}O_2$), minute ventilation (\dot{V}_E) and lactate accumulation during exercise.

The Borg 6-20 RPE Scale is a widely accepted means of assessing the overall (i.e., includes signals from the cardiovascular and respiratory systems and exercising muscles (Borg, 1982)) and localised (i.e., includes signals from the exercising muscles only (Ekblom and Goldbarg, 1971)) sensations of effort during exercise. This scale was constructed in such a way to correlate with physical and physiological markers of exercise intensity, especially with regard to heart rate (Borg, 1998). In this respect, strong linear relationships between the RPE and these physical (i.e., power output (PO) and speed) and physiological (i.e., HR, $\dot{V}O_2$ and \dot{V}_E) markers of exercise intensity are evident during leg cycling (Faulkner and Eston, 2007), walking and running on a treadmill (Horstman et al., 1979) and during arm cranking exercise (Borg et al., 1987). Based on these strong relationships between the RPE and physical and physiological indices of exercise intensity, it can be concluded that the RPE can be effectively used to complement heart rate in regulating exercise intensity. In this regard, the RPE is

included in the guidelines of exercise testing and prescription of the British Association of Sport and Exercise Science (BASES, 2007) and the American College of Sports Medicine (ACSM, 2010).

The aims of this thesis were to expand and apply some of the new aspects in the field of perceived exertion to arm cranking exercise in able-bodied and paraplegic individuals.

- The first aim was to assess the strength of the relationship between the RPE and physical and physiological markers of exercise intensity during arm cranking exercise in able-bodied and paraplegic individuals.
- The second aim was to assess the accuracy of predicting peak oxygen uptake ($\dot{V}O_2\text{peak}^*$) from sub-maximal RPE and $\dot{V}O_2$ values when extrapolated to RPE of 20 (maximal RPE) using both *estimation* and *production* procedures in able-bodied and paraplegic individuals.
- The third aim was to assess the scalar property of the RPE during arm cranking exercise while exercising at two different constant-load exercise intensities in able-bodied and paraplegic individuals.

Therefore, to achieve these goals this thesis comprises a series of six studies. A brief synopsis of the aims and rationale of each study follows:

Study 1: *The relationship between perceived exertion and physical and physiological markers of exercise intensity during arm cranking and leg cycling in able-bodied and paraplegic individuals*

The findings regarding the utility of the RPE with disabled individuals are equivocal. In this regard, Lewis et al. (2007) did not observe a strong relationship between the RPE and physiological indices of exercise intensity during incremental, discontinuous arm cranking exercise in individuals with tetraplegia ($n = 10$) and

* $\dot{V}O_2\text{peak}$ is a preferred term for arm cranking exercise due to the smaller muscle mass activated during arm exercise compared to leg cycling and running or walking on treadmill

paraplegia ($n = 32$). Similarly, Jacobs et al. (1997) observed very strong linear relationship between heart rate and $\dot{V}O_2$ ($r = 0.92$) and moderate linear relationship between the RPE and $\dot{V}O_2$ ($r = 0.51$) in eleven participants with lesions at or below the fourth thoracic vertebra (T4) during shuttle walking exercise using functional neuromuscular stimulation. Jacobs et al. (1997) suggested that the heart rate, and not the RPE, should be used to regulate exercise intensity in these individuals. However, a recent study by Goosey-Tolfrey et al. (2010) did not observe significant differences in HR, %HR, $\dot{V}O_2$, % $\dot{V}O_2$ and blood lactate level between prescribed exercise intensities based on 50% $\dot{V}O_{2\text{peak}}$ (moderate) and 70% $\dot{V}O_{2\text{peak}}$ (vigorous) and RPE-regulated sessions in eight paraplegic men.

These equivocal findings regarding the utility of the RPE with disabled individuals have constituted the rationale for this study. Hence, the main aim of this study was to assess the relationship between the RPE and physical (i.e., PO) and physiological (i.e., HR, $\dot{V}O_2$ and \dot{V}_E) indices of exercise intensity in able-bodied and paraplegic individuals during arm cranking ramp exercise test. The secondary aims of this study were to assess the physiological and physical differences between arm cranking exercise and leg cycling and to assess whether there was a difference in the strength of the relationship between the RPE and physiological markers of exercise intensity between arm cranking exercise and leg cycling in able-bodied individuals.

Study 2: Prediction of peak oxygen uptake from ratings of perceived exertion during arm exercise in able-bodied and persons with paraplegia

Maximal oxygen uptake is the highest rate of oxygen that a person can take up and utilise during exercise involving large muscle groups (Åstrand et al., 2003). It has been indicated that $\dot{V}O_{2\text{max}}$ is the best indicator of cardiorespiratory fitness (Wilmore and Costill, 2004; ACSM, 2010). It has also been indicated that $\dot{V}O_{2\text{max}}$ is an independent predictor of death in patients with heart disease as well as in all causes of

death (Vanhees et al., 1994; Kavanagh et al., 2002). For reasons of cost, time and safety it is preferable sometimes to predict $\dot{V}O_2\text{max}$ using sub-maximal values which are known to have a strong linear relationship with $\dot{V}O_2$ (i.e., heart rate and RPE) by extrapolating these values to age-predicted, maximal heart rate (HRmax) and to RPE of 20 (maximal RPE), respectively.

It is well established that arm exercise elicits a lower peak heart rate compared to leg cycling and running on a treadmill (Franklin, 1985). Similarly, individuals with high spinal cord injury (SCI), above the sixth thoracic vertebra (T6), have attenuated heart rate with maximal heart rate ranges between $120 \text{ b}.\text{min}^{-1}$ to $130 \text{ b}.\text{min}^{-1}$. Therefore, the prediction of $\dot{V}O_2\text{peak}$ from sub-maximal heart rate values, when extrapolated to age-predicted HRmax, will eventually lead to higher estimations of $\dot{V}O_2\text{peak}$ in arm exercise and in individuals with high spinal cord injury.

The strong linear relationship between the RPE and $\dot{V}O_2$ has encouraged some researchers to assess the possibility of predicting $\dot{V}O_2\text{max}$ from sub-maximal RPE values by extrapolating these values to RPE of 20 (Morgan and Borg, 1976; Noble et al., 1981). Interest in this area was renewed by Eston and colleagues (Eston et al., 2005, 2006, 2008; Faulkner and Eston, 2007; Faulkner et al., 2007; Lambrick et al., 2009), Coquart et al., 2009 and Morris et al. (2009, 2010). In general, these authors did not observe a significant difference between measured and predicted $\dot{V}O_2\text{max}$ from sub-maximal RPE values when extrapolated to both maximal RPE (i.e., RPE20) and peak RPE (i.e., RPE19). These authors suggested that $\dot{V}O_2\text{max}$ may be predicted from sub-maximal RPE values with reasonable accuracy. In addition, these authors observed that sub-maximal RPE values provided good estimations of $\dot{V}O_2\text{max}$ which were as good as those predicted from sub-maximal heart rate when extrapolated to age-predicted HRmax. In this regard, it is notable that as early as the mid 1970s, Morgan and Borg, (1976) and Noble et al. (1981) indicated that sub-maximal RPE values provided a more accurate prediction of $\dot{V}O_2\text{max}$ compared to heart rate during leg cycling in men and women.

Arm exercise elicits a lower peak heart rate compared to leg cycling. Also, individuals with high spinal cord injury have a remarkably lower HRpeak, which may in turn affect the prediction of $\dot{V}O_2$ peak from sub-maximal heart rate values when extrapolated to age-predicted maximal heart rate. In addition, all the research regarding the utility of the RPE to predict $\dot{V}O_2$ max has been carried out during leg cycling and running on treadmill in healthy able-bodied individuals. Therefore, the aim of this study was to assess the accuracy of predicting $\dot{V}O_2$ peak from sub-maximal RPE values elicited during a ramp arm cranking exercise test when extrapolated to RPE20. We were also interested in exploring whether the participants' group (i.e., able-bodied and paraplegic) and/or gender moderated the findings.

Study 3: *Prediction of peak oxygen uptake from the ratings of perceived exertion during a graded and ramped exercise test protocol in able-bodied and persons with paraplegia*

The aim of the third study was to assess the accuracy of predicting $\dot{V}O_2$ peak from sub-maximal RPE values elicited during a graded exercise test and a ramp exercise test. Further aims of this study were to assess whether peak physiological, perceptual and physical values observed at the termination of the ramp exercise test and the graded exercise test differed and whether these observations were moderated by participants' group (i.e., able-bodied and paraplegic).

Study 4: *The validity of predicting peak oxygen uptake from a perceptually-guided, graded exercise test during arm cranking exercise in able-bodied and paraplegic individuals*

The second and the third studies employed *estimation* procedures, a passive process in which an individual is asked to appraise how 'hard' or 'easy' an exercise feels (Ceci and Hassmén, 1991), to assess the accuracy of predicting peak oxygen uptake during arm cranking exercise in able-bodied and paraplegic persons. In

addition, it has been indicated that $\dot{V}O_2$ peak may be predicted with reasonable accuracy from a sub-maximal perceptually-guided, graded exercise test during leg cycling (Eston et al., 2005, 2006, 2008; Faulkner et al., 2007) and running on treadmill (Morris et al., 2009). Therefore, the aim of the fourth study was to assess the accuracy of predicting $\dot{V}O_2$ peak from sub-maximal $\dot{V}O_2$ values elicited during a sub-maximal perceptually-guided, graded exercise test. In this case, ‘perceptually-guided’ refers to an active process in which an individual is asked to produce and maintain an exercise intensity equal to a prescribed RPE. The advantage of this exercise test is that individuals have control of the exercise intensity which may in turn improve their exercise adherence. This has important implications for paraplegic individuals as it has been indicated that depression is common among these individuals (Bombardier et al., 2004; Birk, 2009; Figoni, 2009), which may affect their motivation to perform a maximal exercise test.

Study 5a: *The validity of estimating peak oxygen uptake from peak power output during arm cranking exercise in able-bodied and paraplegic individuals using the ACSM equation*

As mentioned above, peak oxygen uptake is the best indicator of cardiorespiratory fitness (Wilmore and Costill, 2004; ACSM, 2010). However, the direct measurement of peak oxygen uptake is expensive. Therefore, some equations have been described to predict peak oxygen uptake from work rate (ACSM, 2006). The aim of this study was to assess the validity of estimating peak oxygen uptake during arm cranking exercise from peak power output in able-bodied and paraplegic individuals using the ACSM equation (ACSM, 2006).

Study 5b: *The validity of predicting peak power output from a perceptually-guided, graded exercise test during arm cranking exercise in able-bodied participants*

In the fourth study we assessed the validity of predicting $\dot{V}O_2$ peak from a perceptually-guided, graded exercise test during arm cranking exercise in able-bodied and paraplegic individuals. The aim of the current study was to assess the accuracy of predicting peak power output from a sub-maximal perceptually-guided, graded exercise test in able-bodied participants. In other words, the aim of this study was to assess the reproducibility of the results which we observed in the fourth study for able-bodied participants.

Study 6: *Ratings of perceived exertion at two different constant-load exercise intensities during arm cranking exercise in able-bodied and paraplegic persons*

Horstman et al. (1979) indicated for the first time that sub-maximal RPE values could be used as a sensitive predictor of time to exhaustion while exercising at constant-load exercise intensity. In their study, 26 men walked and ran at 80% $\dot{V}O_2$ max until volitional exhaustion to ensure generalizability of the results (group 1). Another group of 28 men walked at 80% $\dot{V}O_2$ max to volitional exhaustion to ensure repeatability of the results (group II). They observed that participants in group I walked for longer duration than those in group II. They also observed that the rate of change in the RPE was similar when expressed as a proportion of time (%time) to volitional exhaustion for both groups. That is, the RPE scales with time. In other words, differences in the rate of change of the RPE, when regressed against absolute time, disappeared when the RPE was regressed against %time.

Interest in this area was renewed by Noakes (2004). Using the results from a previously published study (Baldwin et al., 2003), although the rate of change in RPE was significantly greater during the carbohydrate-depleted compared to carbohydrate-repleted condition, he observed no difference in the rate of change in RPE when it was regressed against the proportion of time to volitional exhaustion while exercising at the

same constant-load (70% $\dot{V}O_2$ peak). Studies have assessed this apparent ‘scalar’ property of the RPE during fresh and pre-fatigued conditions while exercising at 75% $\dot{V}O_2$ peak to volitional exhaustion (Eston et al., 2007) and during races of different distances (Faulkner et al., 2008). Other investigators have assessed the rate of change in the RPE under different environmental conditions such as cycling to volitional exhaustion in cool and hot ambient temperatures (Crewe et al., 2008) and during simulated time trials while breathing hypoxic and normal air (Joseph et al., 2008). All these studies confirmed that the RPE increases as a proportion of the time remaining to volitional exhaustion.

The scalar property of the RPE has yet to be assessed during arm cranking exercise in able-bodied and paraplegic individuals. Therefore, the main aim of the sixth study was to assess the rate of change in the RPE (both overall and peripheral RPE) when regressed against absolute time and proportion of time (%time) to volitional exhaustion while exercising at two different constant-load exercise intensities which were structured to elicit different exercise durations. The second aim of this study was to assess the physiological and perceptual responses to constant-load arm cranking exercise in able-bodied and those with paraplegia while exercising at two different constant-load exercise intensities.

Chapter 2

Literature review

2.1 Upper body exercise

A number of studies have considered the responses to upper body exercise in the last three decades (Dicarlo, 1982; Dicarlo et al., 1983; Franklin et al., 1983; Vander et al., 1984; Franklin, 1985; Eston and Brodie, 1986; Sawka, 1986; Franklin, 1989; Aminoff et al., 1996; Muraki et al., 2004). Upper body exercise is a justified mode of exercise testing and prescription for people who use their upper body regularly during exercise, such as rowers, swimmers and kayakers. Similarly, for those who do some kind of work which requires using the upper body such as digging and snow shovelling. Furthermore, it is an appropriate mode of exercise testing and prescription for specific populations who are unable to use their legs during exercise. For instance, individuals with paraplegia as a result of Spinal Cord Injury (SCI) or Spinal Cord Disease (SCD) as well as for those with bilateral above-knee amputees (Hopman, 1994).

2.1.1 Upper body responses to maximal exercise

A maximal exercise test is an exercise test designed to measure maximal values such as maximal oxygen uptake ($\dot{V}O_{2\max}$), maximal heart rate (HR_{max}) and maximal power output (PO_{max}). The duration of the maximal exercise test should be between 8 to 12 minutes as recommended by the ACSM (ACSM, 2010). Two protocols are usually employed to run the maximal exercise test: the ramp protocol and the step-wise protocol. The aim of the research will often determine the most appropriate protocol to be used. For example, if a steady-state response of heart rate (HR) and oxygen uptake ($\dot{V}O_2$) is needed, the step-wise protocol should be used (Eston et al., 2009). A steady-state response of heart rate and $\dot{V}O_2$ is usually attained while exercising for 3 min at each stage (Eston et al., 2009). However, this steady-state response is affected by other factors such as, age (i.e., children achieve steady-state within 1 to 2 min), exercise intensity (i.e., steady-state response achieved sooner at lower intensities) and fitness levels (Eston et al., 2009). In contrast, if the gas exchange

threshold (GET) needs to be determined, a ramp exercise protocol should be utilised since the break point in the linear relationship between the $\dot{V}O_2$ and carbon dioxide ($\dot{V}CO_2$) is clearer compared to the step-wise protocol (Jones et al., 2009).

Usually upper body exercise in able-bodied elicits lower peak values for $\dot{V}O_2$, heart rate, ventilation (\dot{V}_E), power output (PO) and a higher systolic and diastolic blood pressure at maximal levels of exercise compared to leg cycling or running on treadmill (Åstrand et al., 1965; Davis et al., 1976; Kitamura et al., 1981; Franklin et al., 1983; Hagan et al., 1983; Vander et al., 1984; Miles et al., 1989; Aminoff et al., 1996; Aminoff et al., 1997; Huonker et al., 1998). However, participants typically report similar maximal RPE values at the termination of the exercise tests during both upper and lower body exercise modes (Franklin et al., 1983; Vander et al., 1984; Aminoff et al., 1996). Aminoff et al. (1996) observed these peak values at the termination of arm cranking exercise test for $\dot{V}O_2$ ml. min^{-1} kg^{-1} (26.8 and 25.3), \dot{V}_E L. min^{-1} (92 and 102), HR b. min^{-1} (172 and 168), PO (88 W and 86 W) and RPE (19 and 19) for young (26.3 y) and older (56.9 y) participants, respectively. The corresponding peak values for leg exercise were, $\dot{V}O_2$ ml. min^{-1} kg^{-1} (43.6 and 36.4), \dot{V}_E L. min^{-1} (129 and 118), HR b. min^{-1} (182 and 170), PO (235 W and 181 W) and RPE (19 and 18) for young and old participants, respectively.

Generally speaking, these differences in the peak values between the two modes of exercise may be attributed to the relatively smaller muscle mass activated during upper body compared to lower body exercise (McArdle et al., 2007). Calbet et al. (2005) have indicated that the lower $\dot{V}O_2$ peak during arm exercise may be attributed to a shorter mean transit time, smaller diffusing area, larger diffusing distance, and higher heterogeneity in blood flow distribution in arm compared to leg exercise but not for O₂ off-loading as it was similar between the two modes of exercise.

There is a discrepancy regarding maximal blood lactate accumulation during the two exercise modes. Some authors have observed that it is higher in arm exercise compared to leg cycling (Hagan et al., 1983); whereas, others have found it lower in

arm exercise compared to leg cycling (Åstrand et al., 1965; Shephard et al., 1992; Aminoff et al., 1996). Åstrand et al. (1965) have explained why blood lactate accumulation should be lower in upper body than lower body exercise. These authors have stated that the maximal muscle lactate concentration in arms should be the same as in the legs. However, the smaller muscle mass in the upper limbs produces less total amount of lactate which dissolves in the same amount of water which therefore gives a lower concentration of lactate in arterial blood.

2.1.2 Upper body responses to sub-maximal exercise

Sub-maximal exercise refers to any level of exercise intensity below peak potentials (i.e., $\dot{V}O_2$ peak, HRpeak and POpeak) and usually it is expressed as a percentage of peak values (e.g., 60% $\dot{V}O_2$ peak, 70% HRpeak and 60% POpeak). This kind of exercise typically lasts for quite a long period of time and its duration depends on the level of exercise intensity. That is, the higher the exercise intensity, the shorter the exercise duration will be and vice-versa.

It has been shown that when both arms and legs exercise at the same sub-maximal work rate or at the same percentage of $\dot{V}O_2$ peak, arms elicit higher values for $\dot{V}O_2$, HR, \dot{V}_E , ventilatory equivalent for oxygen ($\dot{V}_E/\dot{V}O_2$), systolic and diastolic blood pressure, blood lactate concentration and RPE (Bobbert, 1960; Åstrand et al., 1965; Bevegard et al., 1966; Åstrand et al., 1968; Rasmussen et al., 1975; Franklin et al., 1983; Hagan et al., 1983; Pandolf et al., 1984; Vander et al., 1984; Eston and Brodie, 1986; Borg et al., 1987). It has also been indicated that anaerobic threshold occurs at a lower exercise intensity (i.e., lower % $\dot{V}O_2$ peak) during arm cranking compared to leg exercise (Davis et al., 1976; Pendergast, 1989). Furthermore, it has been indicated that stroke volume is lower during arm exercise compared to leg cycling (Bevegard et al., 1966; Stenberg et al., 1967; Davies and Sargeant, 1974; Miles et al., 1989).

Franklin et al. (1983) and Vander et al. (1984) assessed sub-maximal exercise responses between arm and leg ergometer during an incremental exercise test to measure $\dot{V}O_2$ peak in 10 men and 10 women, respectively. These authors observed

that at a given sub-maximal work rate, arm exercise elicited higher values for oxygen uptake, ventilation, heart rate, Respiratory Exchange Ratio (RER) and RPE compared to leg exercise, irrespective of gender. At 450 kpm.min⁻¹ (~74 W), Franklin et al. (1983) observed higher values for $\dot{V}O_2$ (1.56 L.min⁻¹ and 1.25 L.min⁻¹), \dot{V}_E (41 L.min⁻¹ and 29 L.min⁻¹), HR (136 b. min⁻¹ and 121 b. min⁻¹), RER (0.94 and 0.92) and RPE (15 and 12) during arm exercise compared to leg cycling in ten men, respectively. At the same exercise intensity, Vander et al. (1984) observed higher values for $\dot{V}O_2$ (1.52 L.min⁻¹ and 1.09 L.min⁻¹), \dot{V}_E (59 L.min⁻¹ and 30 L.min⁻¹), HR (169 b. min⁻¹ and 137 b. min⁻¹), RER (1.11 and 0.98) and RPE (18 and 13) during arm exercise compared to leg cycling in ten women, respectively.

Eston and Brodie, (1986) studied the exercise responses to three different work rates (i.e., ~50 W, ~75 W and ~100 W) between arms, legs and combined arm and leg exercise. They observed significantly higher $\dot{V}O_2$, \dot{V}_E , HR and RPE and a significantly lower gross mechanical efficiency during arm exercise compared to leg cycling and combined arm and leg exercise. From the study by Borg et al. (1987), at exactly the same absolute work rates (i.e., 70 W and 100 W), there was a clear difference in the physiological and perceptual responses between arm and leg exercise. At 70 W, HR values were 108 and 136 b.min⁻¹, blood lactate accumulation values were 1.1 and 5.6 mmol. L⁻¹ and RPE values were ~11 and ~16 for leg and arm exercises, respectively. At 100 W, HR values were 123 and 171 b.min⁻¹, blood lactate accumulation values were 1.3 and 9.9 mmol. L⁻¹ and RPE values were ~13 and ~18 for leg and arm exercises, respectively.

As arm exercise elicits a lower $\dot{V}O_2$ peak, when both arms and legs exercise at the same work rate, the arms work at higher percentage of $\dot{V}O_2$ peak. That is, arms must work relatively harder to produce the same work rate as in leg exercise, which increases blood flow and raises blood lactate. This in turn causes the person to experience greater sensations of exertion (Borg et al., 1987).

Higher sub-maximal $\dot{V}O_2$ values during upper body compared to lower body exercise may be attributed to the recruitment of ancillary muscles for stabilizing the torso (McArdle et al. 2007), from the lower-mechanical efficiency from static work of the trunk and other muscles which increase oxygen consumption and do not contribute to the measurable external work rate (Bevegard et al., 1966; Eston and Brodie, 1986).

The higher sub-maximal heart rate values during upper body compared to lower body exercise may be attributed to the lower stroke volume of the heart owing to a reduced venous return to the heart due to orthostatic pressure (Stenberg et al., 1967). In addition, Davies and Sargeant, (1974) have indicated that the lower stroke volume may be attributed to an inadequate muscle pumping mechanism during upper body exercise, which in turn will reduce venous return. Bevegard et al. (1966) have indicated that the higher sub-maximal heart rate values could be related to a higher sympathetic outflow and higher ventilation during arm exercise compared to leg exercise.

Higher sub-maximal \dot{V}_E values during arm exercise are achieved by an increase in the respiratory rate with lower tidal volume (Davies and Sargeant, 1974; Pendergast, 1989). Higher sub-maximal \dot{V}_E values during upper body exercise compared to leg exercise might be attributed to the higher blood lactate concentration (Stenberg et al., 1967) and higher sympathetic outflow during arm exercise (Davies et al., 1974). In addition, there are other factors which might affect ventilation during arm cranking such as the synchronization between rhythmic arm movement and the respiratory rate (Vokac et al., 1975; Mangum, 1984) and limitation of tidal volume owing to static movement of the abdominal, pectoralis and other muscles in the torso and shoulder girdle (Mangum, 1984). Bevegard et al. (1966) have indicated that higher \dot{V}_E may be an important factor in maintaining ventricular filling pressure and maintain the stroke volume in the absence of leg pumping mechanism.

2.1.3 Adaptations to arm exercise

Regular upper body exercise, as observed with other modes of exercise, can bring about specific adaptations to the cardiovascular and the respiratory systems for

both able-bodied and disabled populations. It has been shown that arm exercise decreases heart rate, $\dot{V}O_2$, $\dot{V}_E/\dot{V}O_2$ and blood lactate accumulation at a given sub-maximal work rate (Clausen et al., 1970; Rasmussen et al., 1975; Klausen et al., 1974; Marion et al., 1986; Dicarlo, 1988). However, it has been indicated that adaptations to exercise are specific to trained muscles (Eston and Romer, 2009). At sub-maximal work rates, Rasmussen et al. (1975) observed a significant decrease in the ventilatory equivalent for oxygen ($\dot{V}_E/\dot{V}O_2$) after arm training during arm exercise, but not during leg exercise. At sub-maximal work rate these authors also observed a significant decrease in $\dot{V}_E/\dot{V}O_2$ after leg training during leg exercise, but not during arm exercise.

The same thing can be stated for heart rate and blood lactate accumulation. At sub-maximal work rates, a period of arm training has resulted in a reduction in HR and blood lactate accumulation during arm exercise. However, this reduction was less pronounced during leg exercise (Clausen et al., 1970; Clausen et al., 1973; Klausen et al., 1974). The aforementioned studies observed reductions in heart rate and blood lactate accumulation after leg training during leg exercise, but it is notable these reductions were less pronounced during arm exercise. The aforementioned studies provide convincing evidence that training adaptations are specific to the muscle groups trained.

These adaptations to arm exercise are more important for disabled persons since they cannot use their lower extremities during exercise owing to their disabilities. Arm training increases peak values for $\dot{V}O_2$, \dot{V}_E and work rate for able-bodied and disabled participants (Dicarlo, 1982; Miles et al., 1982; Dicarlo et al., 1983; Dicarlo, 1988; Loftin et al., 1988; Kriz et al., 1992; Schmid et al., 1998; Valent et al., 2008). After 5 weeks of arm training at 70%, 80% and 90% of the Heart Rate Reserve (HRR), Loftin et al. (1988) observed a significant increase in the peak values of $\dot{V}O_2$ (32%), stroke volume (11%), cardiac output (14%), \dot{V}_E (33%), cumulative power output (79%) and arterial-venous oxygen difference (16%) in a training group of 19 healthy, able-bodied women during peak arm exercise. However, these authors observed minimal

changes in the aforementioned variables in a control group of 19 healthy able-bodied women. In addition, Dicarlo et al. (1983) observed a significant increase in peak power output (64%) and in $\dot{V}O_2$ peak (61%) after five weeks of arm training at 60% to 80% of HRpeak during maximal exercise testing in four men with spinal cord injury. Furthermore, Dicarlo (1988) observed a significant increase in POpeak, $\dot{V}O_2$ peak and distance covered (in kilometres) during 12 minutes of wheelchair-propulsion endurance exercise test in eight men with tetraplegia after eight weeks of arm cranking training at 50% to 60% of the heart rate reserve.

At sub-maximal levels, it has been indicated that arm training decreases heart rate at rest and at the same absolute sub-maximal work rate, which in turn reflects a more efficient work of the heart (Clausen et al., 1970; Clausen et al., 1973; Klausen et al., 1974; Dicarlo, 1982; Marion et al., 1986; Dicarlo, 1988). In this aspect, Hookers and Wells, (1989) observed that eight weeks of wheelchair ergometry training at moderate exercise intensity decreased heart rate, rating of perceived exertion and lactate accumulation at identical sub-maximal work rates in three men and two women with spinal cord injury. These authors also observed a significant increase in HDL-C and decrease in LDL-C and triglyceride after training. These changes in blood lipidemia (i.e., decreased LDL-C and increased HDL-C) will in turn decrease the risk of developing coronary heart disease (Heldenberg et al., 1981; British Association of Cardiac Rehabilitation, 2008), which is common among these individuals (Le and Price, 1982). In addition, Dicarlo (1988) observed a significant decrease in heart rate at identical sub-maximal work rates in eight men with tetraplegia after eight weeks of arm cranking training at 50% to 60% of the peak heart rate reserve.

2.1.4 Supine vs. upright exercise

There are specific physiological and perceptual differences in exercise responses between supine and upright position during both leg cycling and arm cranking. It has been indicated that resting stroke volume was higher and resting heart rate was lower in the supine compared to the upright position (Poliner et al., 1980; Bevegard et al., 1966). It has also been indicated that peak heart rate is lower and

peak stroke volume is higher during supine compared to upright position (Stenberg et al., 1967; Poliner et al., 1980; Takahashi et al., 1995).

Disabled participants found it easier to exercise in a supine compared to a sitting position during arm exercise (McLean et al., 1995). Figoni et al. (1991) also observed significantly higher peak values for power output, oxygen uptake, cardiac output and stroke volume in a supine compared to a sitting position during maximal arm ergometry exercise in individuals with quadriplegia. Similarly, McLean et al. (1995) observed a significantly higher peak values for $\dot{V}O_2$, \dot{V}_E and PO during supine compared to a sitting position in a similar group of participants. They indicated that the higher $\dot{V}O_2$ peak may be attributed to increased ventilation, greater venous return and a greater stability of the torso in the supine compared to the sitting position. These authors also observed that the relationship between heart rate and $\dot{V}O_2$ tends to be higher during the supine ($r = 0.90$) compared to the sitting position ($r = 0.79$).

However, Pendergast et al. (1979) observed a lower $\dot{V}O_2$ peak in the supine compared to the sitting position during arm exercise with able-bodied participants. These authors speculated that this may be attributed to the increased vertical distance between the heart and the exercising muscles which decreases the perfusion of the arms' muscles and consequently reduces peak oxygen uptake.

2.2 Perceived exertion

2.2.1 The concept of perceived exertion

Perceived exertion can be defined as the degree of effort, stress or discomfort that is felt during exercise (Noble and Robertson, 1996). Borg (1970, 1998) has indicated that physical work involves three continua - the perceptual (psychological), performance (environment) and physiological.

The perception is a basic continuum in exploring the origin of the rating of perceived exertion (Borg, 1998; Eston and Parfitt, 2007). In other words, rating of perceived exertion is a subjective indicator based on the physiological and

performance continua. This is a fundamental continuum since our response to different situations is influenced by our personal subjective experience and is also affected by previous experiences of similar situations (Borg, 1998; Eston and Parfitt, 2007). Therefore, to assess strain and stress you have to start identifying the dilemma by asking individuals regarding their experiences of stressful situations and their responses to those situations (Borg, 1998). As such, during exercise it is very important to ask an individual how he/she feels during exercise and not to rely only on the physiological markers of exercise intensity.

The performance continuum includes maximal performance which basically describes an individual's maximal potential. Examples of maximal performance are the highest exercise intensity a person can sustain for a period of time, the shortest time a person can run a given distance and the longest distance the person can run in a given time (Eston and Parfitt, 2007). Maximal performance is easy to specify and to measure compared to sub-maximal exercise. On the other hand, any level of exercise below the person's maximal potential is considered as a sub-maximal performance (e.g., 70% $\dot{V}O_{2\text{max}}$, 50% HRR and 50% PO_{max}). When a person runs or walks at his or her preferred intensity is an example of sub-maximal exercise performance. Sub-maximal performance is relatively more difficult to define compared to maximal exercise (Borg, 1998).

The physiological continuum includes many variables such as $\dot{V}O_2$, \dot{V}_E , HR, $\dot{V}_E/\dot{V}O_2$, lactate concentration in blood and muscles and PH. Physiological parameters are more easily measured compared to the variables which belong to the perceptual continuum (Borg, 1998). Some of these physiological variables have linear relationships with the physical parameters of PO, energy expenditure and speed, such as heart rate and $\dot{V}O_2$, whereas, other variables increase as a non-linear function with increments in exercise intensity, such as lactate accumulation (Borg, 1998). Although it is quite easy to measure the physiological variables, it is not very easy to integrate these variables to predict performance (Borg, 1998). However, the overall perception of

effort integrates many cues from all over the body and automatically gives special weight to the most important ones (Borg, 1982, 1998). These three continua are described in Figure 2.1.

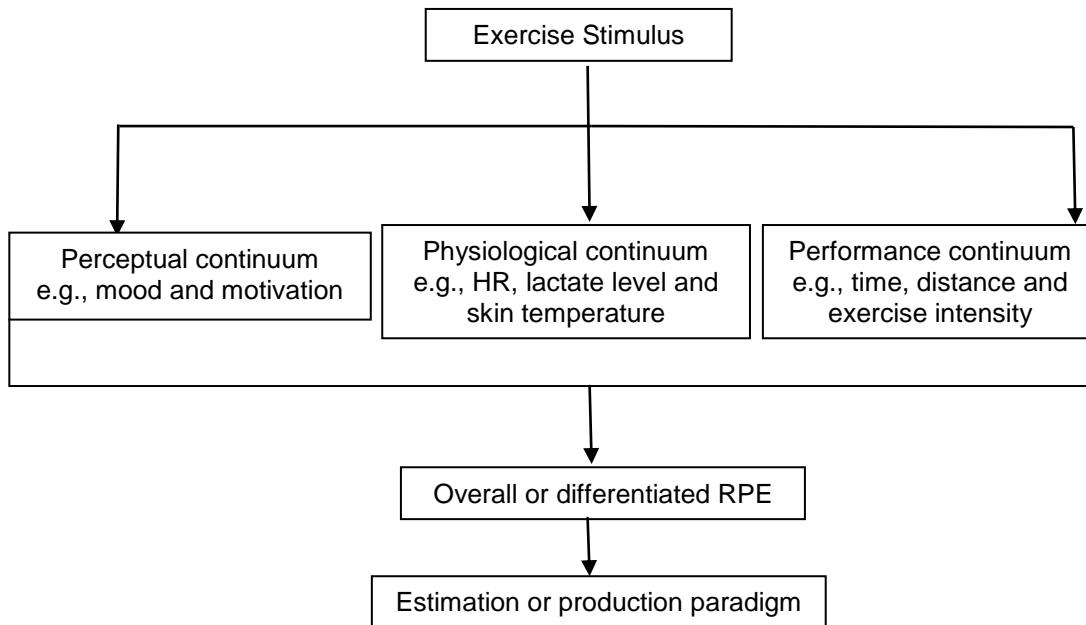


Figure 2.1: The three effort continua: perceptual, physiological and performance. Note: modified from Perceived Exertion (Eston and Parfitt (2007 pp.276)). In N. Armstrong (ed), *Paediatric Exercise Physiology* (pp. 275-298).

2.2.2 The measurement of perceived exertion

The measurement of perceived exertion is the degree of heaviness and strain experienced in physical work as estimated according to a specific perceptual scale such as Borg 6-20 RPE Scale (Borg, 1998). The Borg 6-20 RPE Scale is a widely used and accepted means of assessing the perception of effort during different modes of exercise, such as leg cycling (Skinner et al., 1973a; Borg et al., 1985; Demura and Nagasawa, 2003; Faulkner and Eston, 2007), arm exercise (Borg et al., 1987; Kang et al., 1999; Goosey-Tolfrey et al., 2010) and during treadmill exercise (Eston et al., 1987; Dunbar et al., 1992, 1994). In addition, it has been used with many different populations, such as children (Gillach et al., 1989; Ward et al., 1991; Williams et al., 1991), adults and old individuals (Aminoff et al., 1996), male and female participants (Koltyn et al., 1991), healthy participants (Okura and Tanaka, 2001), diseased participants (Löllgen et al., 1977), individuals with physical disability (Jacobs et al.,

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1997; Goosey-Tolfrey and Kirk, 2003; Lewis et al., 2007; Lenton et al., 2008), individuals with vision impairment (Buckley et al., 2000) and in low- and high-fit participants (Faulkner et al., 2007). As such, the Borg 6-20 RPE scale (Borg, 1998) was used in all the studies contained in this thesis. The Borg 6-20 RPE scale was translated to the Arabic language by the researcher and approved by an authorised translator. The translated Arabic version was used during the first and the second studies and for paraplegic individuals in the third, fourth, fifth and seventh studies. It was deemed to be appropriate to include both the English and the Arabic versions of the Borg 6-20 RPE Scale in this chapter (Table 2.1).

Table 2.1: The Borg 6-20 RPE scale and the corresponding Arabic version. Note: modified from *Borg's Perceived Exertion and Pain Scales* (Borg, 1998).

Borg 6-20 RPE scale	مقاييس معدل إدراك الجهد البدني لبورغ
6 No exertion at all	6 لا يوجد جهد على الإطلاق
7	7 خفيف جداً جداً
Extremely light	
8	8 خفيف جداً
9 Very light	9 صعب جداً
10	10 صعب
11 Light	11 صعب
12	12 صعب جداً جداً
13 Somewhat hard	13 صعب بعض الشيء
14	14 صعب جداً جداً
15 Hard (heavy)	15 صعب (ثقيل)
16	16 صعب جداً جداً
17 Vey hard	17 صعب جداً جداً
18	18 صعب جداً جداً
19 Extremely hard	19 صعب جداً جداً
20 Maximal exertion	20 الجهد الأقصى

Where 6 “*no exertion at all*” like when we are sitting, relaxing and not doing anything; 9 “*very light feeling*” like when you walk on your own pace; 13 “*somewhat hard*” it feels okay and you can continue exercising for quite long period of time; 17 “*very hard*” at this stage you feel tired so you need to push yourself to go; 19 “*extremely hard*” corresponds to the most strenuous exertion you have ever experienced and 20 “*maximal exertion*” corresponds to the theoretically maximal feeling of exertion (Borg, 1998).

2.2.3 Central, local and overall ratings of perceived exertion

The ratings of perceived exertion are frequently differentiated as central, localised and overall ratings of effort. The assessment of central perceived exertion is used to assess the sensory cues from cardiovascular and respiratory systems such as heart rate, oxygen uptake, ventilation and respiratory rate (Ekblom and Goldbarg, 1971; Pandolf, 1978; Pandolf, 1982; Robertson, 1982; Robertson et al., 1979b). The assessment of localized perceived exertion includes sensory cues from the exercising muscles and joints, and is used to detect the localized sensations attributed to the accumulation of blood lactate, changes in skin temperature, blood and muscle PH and exercise-induced muscle damage (Ekblom and Goldbarg, 1971; Pandolf, 1978; Pandolf, 1982; Robertson et al., 1979b; Hampson et al., 2001). Finally, the overall measure of perceived exertion is used to reflect the integration of the sensory cues from all over the body (i.e., both central and localised perceived exertion, Borg, 1982).

Ekblom and Goldbarg, (1971) indicated that localised perceived exertion is dominant during exercise involving smaller muscle groups; whereas, central perceived exertion is dominant during exercise involving large muscle bulks. It has also been indicated that local or peripheral perceived exertion is usually higher than either central or overall perceived exertion (Ekblom and Goldbarg, 1971; Knuttgen et al., 1982; Pandolf et al., 1984; Shephard et al., 1992; Mahon et al., 1998; Demura and Nagasawa, 2003; Green et al., 2003; Faulkner and Eston, 2007). That seems to be evident regardless of exercising at different pedal cadence (i.e., 40, 60 and 80 rpm, Robertson et al., 1979a).

2.2.4 Perceived exertion and exercise modality

Perceived exertion is affected by the exercise being performed. In this respect, Ekblom and Goldbarg, (1971) have indicated that participants perceived exercise to be harder during arm cranking exercise compared to leg cycling. These findings were also confirmed in the study by Eston and Brodie, (1986) and later by Borg et al. (1987). This response may be explained by the relationship between the subjective feeling of strain during exercise and the metabolic rate per unit of contracting muscle mass (Åstrand et al., 2003). When the muscle mass is small, such as during arm exercise, the upper limbs fatigue more rapidly. As demonstrated in Figure 2.2, at approximately the same heart rate, a higher RPE (approximately 1.5-2.0 units) is reported during arm compared to leg exercise (Borg et al., 1987).

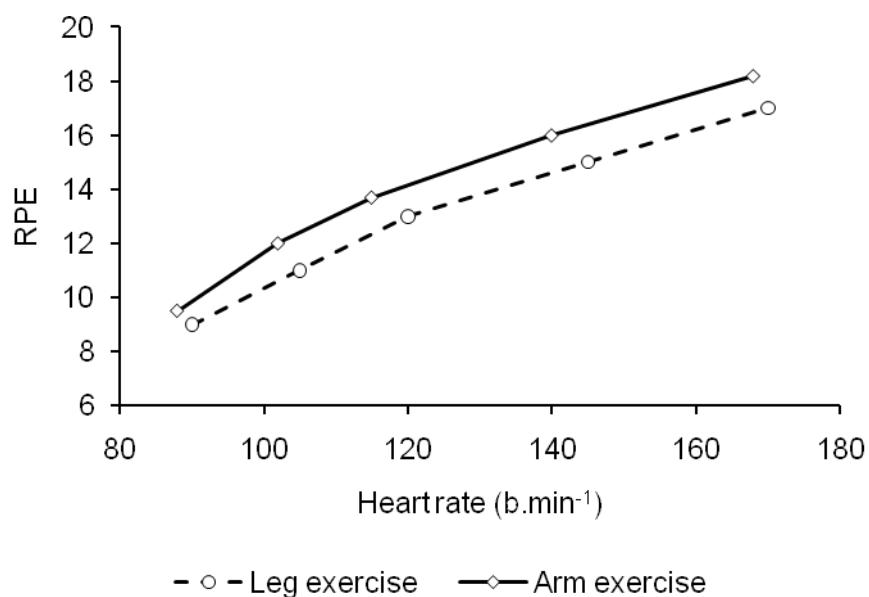


Figure 2.2: RPE responses during arm cranking and leg exercise at different heart rates. Note: modified from Borg et al. (1987). *European Journal of Applied Physiology*, **65**, 679-685.

2.2.5 Perceived exertion and physiological markers of exercise intensity

There are strong relationships between the ratings of perceived exertion and physiological and physical markers of exercise intensity (Bar-Or et al., 1972; Skinner et al., 1973a; Skinner et al., 1973b; Ulmer et al., 1977; Hassmén, 1990). These relationships are usually attained during *estimation* procedures. The *estimation*

procedure is a passive process in which individuals indicate how ‘hard’ an exercise bout feels to them according to a specific perceptual scale (Ceci and Hassmén, 1991). Strong linear relationships between the RPE and physical and physiological variables are also evident during *production* procedures in the form of a perceptually-guided, graded exercise test proposed by Eston and colleagues (Eston et al., 2005, 2006, 2008) and Morris et al. (2009, 2010). In the perceptually-guided, graded exercise test, participants are asked to produce and maintain an exercise intensity equal to a predetermined RPE; usually equal to 9, 11, 13, 15 and 17 (Eston et al., 2005, 2006; Faulkner et al., 2007, 2009; Morris et al., 2009, 2010).

2.2.5.1 Perceived exertion and oxygen consumption

Maximal oxygen uptake ($\dot{V}O_2\text{max}$) is the highest rate at which an individual can consume, transport and utilize oxygen during exercise involving large muscle groups (Åstrand et al., 2003). It has been indicated that maximal oxygen uptake is the best criterion of measuring physical and cardiorespiratory fitness (Wilmore and Costill, 2004; Cooke, 2009; ACSM, 2010). It has also been indicated that $\dot{V}O_2\text{max}$ can be affected by number of factors such as age, gender, mode of exercise, heredity, state of training, body size and composition (McArdle et al., 2007).

Young participants have higher $\dot{V}O_2\text{max}$ than their older counterparts (Aminoff et al., 1996) and men have higher $\dot{V}O_2\text{max}$ than women (Hagan et al., 1983; Robertson et al., 2000; Green et al., 2003). Physically active participants have higher $\dot{V}O_2\text{max}$ than their sedentary counterparts, irrespective of gender or age (Faulkner and Eston, 2007). It has also been indicated that running on treadmill produces a higher $\dot{V}O_2\text{max}$ than leg cycling and arm cranking (Robertson et al., 2000; Green et al., 2003). Furthermore, individuals who have more slow-twitch muscle fibres will have higher $\dot{V}O_2\text{max}$ than their counterparts who have more muscle fibres of fast-twitch type (Wilmore and Costill, 2004). Theoretically, two people of the same fitness level will have similar relative $\dot{V}O_2\text{max}$ values (i.e., $\text{ml}.\text{kg}^{-1}.\text{min}^{-1}$). However, when expressed in

absolute terms (i.e., L.min⁻¹), the larger individual will have a higher $\dot{V}O_2$ max value compared to his or her smaller counterpart.

Oxygen uptake is one of the central cues that moderate the RPE during exercise (Mihevic, 1981; Pandolf, 1982; Robertson, 1982; Hampson et al., 2001). Previous research has indicated that there is a strong linear relationship between $\dot{V}O_2$ and RPE during estimation (Skinner et al., 1973a; Skinner et al., 1973b; Demura and Nagasawa, 2003; Ueda and Kurokawa, 1995) or production procedures (Eston et al., 2005, 2006, 2008; Morris et al., 2009, 2010). It has also been indicated that this relationship between these two parameters is not a direct one (Robertson, 1982). Rather, these two variables have a linear relationship because both of them increase as a function of work rate (Robertson, 1982). That is, oxygen consumption can not be consciously perceived during exercise, in contrast to the minute ventilation or respiratory rate which could be consciously perceived during exercise by the exerciser (Mihevic, 1981; Robertson, 1982; Carton and Rhodes, 1985; Hampson et al., 2001).

An interesting point regarding the relationship between oxygen uptake and the RPE is that most of the differences observed in the RPE between individuals in absolute term (i.e., $\dot{V}O_2$) are diminished when this comparison is made in relative terms – for example, as a proportion of the maximal oxygen uptake (% $\dot{V}O_2$ max). For example, females reported higher RPE compared to males (Sidney and Shephard, 1977; Noble et al., 1981); lean participants reported higher RPE during leg cycling compared to their obese counterparts (Skinner et al., 1973b); old individuals, regardless of gender, reported higher RPE compared to their younger counterparts (Sidney and Shephard, 1977) when comparisons were made in absolute terms of $\dot{V}O_2$. However, when these groups were compared when $\dot{V}O_2$ was expressed as a proportion of maximal oxygen uptake (% $\dot{V}O_2$ max) the differences in the RPE were removed (Skinner et al., 1973b; Sidney and Shephard, 1977; Noble et al., 1981). Noble et al. (1981) suggested that perceived exertion responses are made based on proportion of maximum abilities used during exercise.

2.2.5.2 Perceived exertion and heart rate

The Borg 6-20 RPE Scale was constructed in such a way to correlate with physical and physiological indices of exercise intensity, especially heart rate (Borg, 1998). Since most of young and middle-aged individuals have a resting heart rate of 60 $b.\text{min}^{-1}$ and a maximal heart rate of 200 $b.\text{min}^{-1}$, each RPE unit may be considered in relation to an interval of 10 beats per minute (Borg, 1998). Heart rate is classified as one of the central cues which mediate the perception of effort (Mihevic, 1981; Pandolf, 1982; Robertson, 1982; Carton and Rhodes, 1985). Although heart rate may be consciously monitored at rest, it is unlikely that heart rate can be consciously perceived during exercise (Robertson, 1982; Noble and Robertson, 1996).

Previous research has shown strong relationships between heart rate and RPE during exercise (Borg, 1970; Bar-Or et al., 1972; Edwards et al., 1972; Skinner et al., 1973a; Skinner et al., 1973b; Costa and Gaffuri, 1977; Eston et al., 1987, 2005, 2006; Faulkner and Eston, 2007). This relationship between HR and RPE is evident in men and women (Faulkner et al., 2007; Lambrick et al., 2009), adults and adolescent boys (Eston and Williams, 1986; Eston et al., 1987); lean and obese individuals (Bar-Or et al., 1972; Skinner et al., 1973a; Skinner et al., 1973b); and during various modes of exercise, such as leg cycling (Bar-Or et al., 1972; Skinner et al., 1973a; Hassmén, 1990; Demura and Nagasawa, 2003), treadmill exercise (Bar-Or et al., 1972; Skinner et al., 1973b; Hassmén, 1990) and arm exercise (Borg et al., 1987).

Since this relationship is not a causative one, many investigations have explored the HR and RPE responses under different conditions. Pandolf et al. (1978) observed higher RPE values during eccentric compared to concentric exercise at the same heart rate. Similarly, Pandolf (1977) and Kamon et al. (1974) observed that at high temperatures (i.e., 44° and 54 C°) the increase in heart rate due to elevated ambient temperatures was not associated with elevation in the RPE responses. However, Skinner et al. (1973b) indicated that the relationship between heart rate and RPE was not affected by heat (i.e., 32 C°). Hampson et al. (2001) indicated that this discrepancy in these findings might be attributed to the fact that the temperatures

utilised in the study by Skinner et al. (1973b) did not reach the threshold temperature which disrupts this relationship between heart rate and RPE. Finally, Noble (1979) found no significant correlation between heart rate and RPE during the recovery period after running to exhaustion in untrained men and women. These observations support the notion that the relationship between heart rate and RPE is not a causative one.

The rating of perceived exertion is sensitive to individuals' heart rate range. As maximal heart rate decreases with age, individuals tend to report higher RPE at a given heart rate (Borg, 1970; Bar-Or et al., 1972; Mihevic, 1981; Hampson et al., 2001). That means older individuals perceive a given exercise intensity to be more strenuous compared to their younger counterparts at a given heart rate.

2.2.5.3 Perceived exertion and ventilation

Minute ventilation (\dot{V}_E L. min^{-1}) is the amount of air that a person can breathe in and out in one minute (Eston and Romer, 2009). It is the product of tidal volume and respiratory rate; \dot{V}_E (L. min^{-1}) = tidal volume \times respiratory rate (Eston and Romer, 2009). It is also considered as an important process in maintaining an adequate gas exchange at alveolar level (Eston and Romer, 2009). Ventilation, like other physiological variables can be affected by other factors such as age, gender and physical activity level. In this aspect, women and children have lower maximal values of ventilation compared to their men and adult counterparts (Wilmore, 2005; Eston and Romer, 2009). These differences in age and gender are mainly attributed to the differences in body size between men and women and between adults and children (Wilmore, 2005; Eston and Romer, 2009).

Minute ventilation, like breathlessness, is one of the central signals that mediate perception of effort and it is debated to be the only central signal that can be consciously monitored during exercise by the exerciser (Mihevic, 1981; Pandolf, 1982; Robertson, 1982; Hampson et al., 2001). Statistically significant correlation coefficients (i.e., 0.61-0.94) between minute ventilation and the RPE have been observed during exercise (Edward et al., 1972; Skinner et al., 1973a; Skinner et al., 1973b; Smutok et al., 1980; Robertson, 1982; Hampson et al., 2001).

2.2.5.4 Perceived exertion and lactate concentration

Lactate concentration is one of the peripheral signals that mediate perceived exertion especially at high exercise intensities (Pandolf, 1982; Noble and Robertson, 1996; Hampson et al., 2001). Previous studies observed a direct relationship between lactate level and RPE with the increase in exercise intensities (Hampson et al., 2001). Lactate level has an exponential relationship with Borg 6-20 RPE Scale (Figure 2.3); whereas, the other physiological variables (i.e., heart rate, $\dot{V}O_2$ and \dot{V}_E) have linear relationships with the RPE (Borg, 1998). Borg et al. (1987) observed a more linear relationship between blood lactate concentration and the Category-Ratio 10 (CR10) Scale (Figure 2.4). This is expected as the CR10 Scale is designed to increase curvilinearly with power output. Typically, leg cycling and arm cranking elicit higher peripheral RPE compared to treadmill exercise and leg cycling, respectively (Ekblom and Goldbarg, 1971; Eston and Brodie, 1986; Borg et al., 1987). This might be attributed to the fact that smaller muscle mass produces more lactate and consequently leads to a higher sensation of effort (Ekblom and Goldbarg, 1971; Borg et al., 1987).

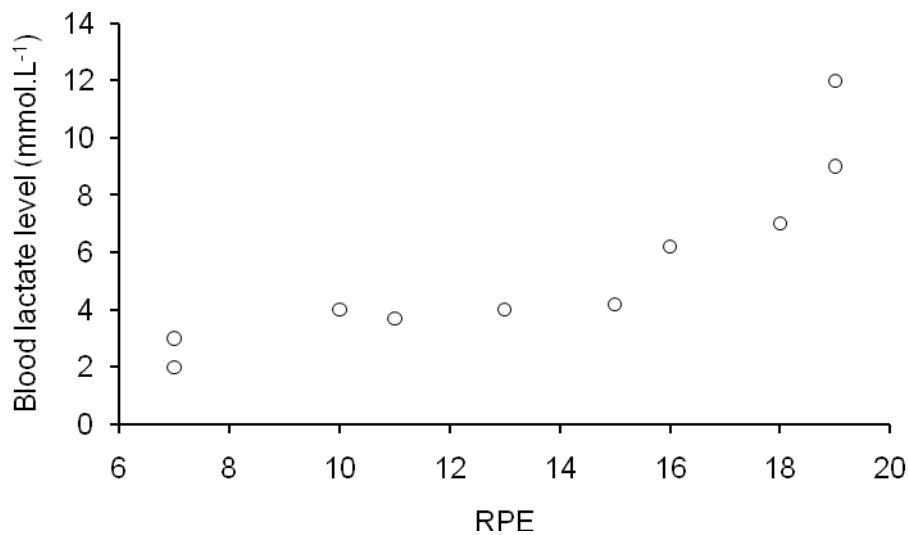


Figure 2.3: An example showing the curvilinear relationship between Borg 6-20 RPE Scale and blood lactate levels during incremental leg cycling exercise test. Note: modified from Eston et al. (2009). In R.G. Eston & T. Reilly (Eds.), *Kinanthropometry and Exercise Physiology Laboratory Manual: Tests, Procedures and Data, Volume 2: Physiology* (pp. 237-270).

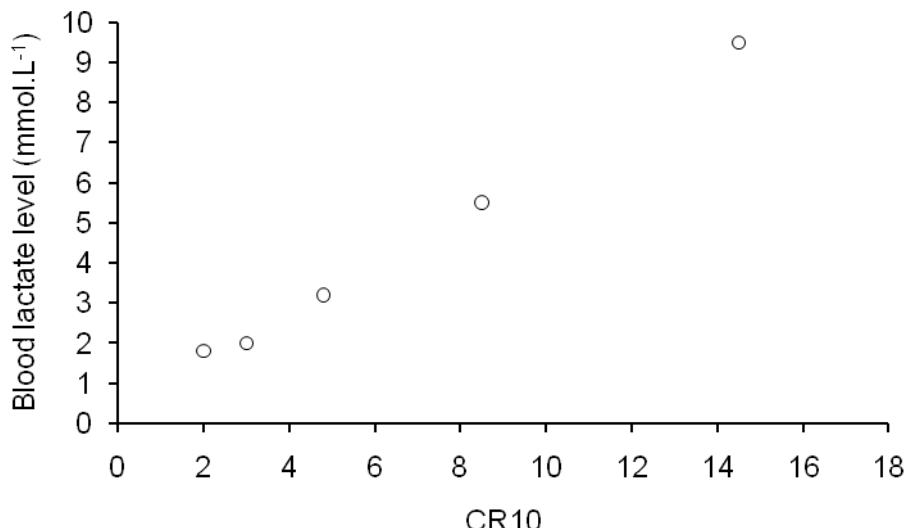


Figure 2.4: An example showing the relationship between CR10 Scale and blood lactate levels during incremental arm cranking exercise test. Note: modified from Borg et al. (1987). *European Journal of Applied Physiology*, **65**, 679-685.

It has been suggested that blood lactate does not influence the RPE directly; rather, it mediates the RPE through the pH changes associated with lactic acid production (Hampson et al., 2001). In this respect, Robertson et al. (1986) observed that the ingestion of NaHCO_3 to induce alkalosis was associated with a reduction in the RPE at an exercise intensity corresponding to 80% $\dot{\text{V}}\text{O}_{2\text{max}}$ during arm, leg and combined arm and leg exercise. Similarly, Kostka and Cafarelli, (1982) observed that the ingestion of NH_4Cl to induce acidosis was associated with a higher sensation of fatigue during the exercise test at 80% $\dot{\text{V}}\text{O}_{2\text{max}}$. These observations suggest that blood pH has an effect on sensation of effort during high exercise intensities (i.e., $\geq 80\% \dot{\text{V}}\text{O}_{2\text{max}}$).

2.2.6 Perceived exertion and gender

It is widely accepted that women have less muscle mass and a higher percentage body fat than men (Janssen et al., 2000; Wilmore, 2005; McArdle et al., 2007). Women also have lower values for blood volume, stroke volume, maximal cardiac output and hemoglobin (Wilmore, 2005). Furthermore, women have a smaller thoracic cavity compared to men (Eston and Romer, 2009) and are generally less active than men (Wilmore, 2005). Hence, men tend to have higher maximal values for

$\dot{V}O_2$, \dot{V}_E and PO compared to women (Washburn and Seals, 1984; Robertson et al., 2000; Faulkner et al., 2007).

Research regarding the rating of perceived exertion and gender is equivocal. It has been indicated that women report higher RPE compared to men at a given absolute $\dot{V}O_2$ or PO values (Sidney and Shephard, 1977; Noble et al., 1981; Ueda and Kurokawa, 1995; O'Connor et al., 1996; Robertson et al., 2000; Faulkner and Eston, 2007). Usually these differences disappear when both men and women are compared at the same percentages of $\dot{V}O_{2\text{max}}$ or PO_{max} (Sidney and Shephard, 1977; Noble et al., 1981; Eston et al., 1987; Winborn et al., 1988; Robertson et al., 2000; Faulkner and Eston, 2007). However, Parfitt et al. (1994) indicated that women report higher RPE values than men at the same percentages of $\dot{V}O_{2\text{max}}$.

Although trained and untrained men and women had similar RPE values at the lactate threshold (~13), women reported 0.5 and 1.2 RPE units higher than men when both were compared at 50, 60, 70, 80, and 90% $\dot{V}O_{2\text{max}}$ but this was not a significant difference (DeMello et al., 1987). In addition, Green et al. (2003) found that men and women have similar overall RPE, leg RPE and chest RPE at the respiratory compensation threshold. However, Purvis and Cureton, (1981) have indicated that men reported a significantly higher RPE (14.2) than women (13.1) at the anaerobic threshold. Regardless of this difference, both the men and women in this study perceived their exercise at the anaerobic threshold to be 'somewhat hard' which is in agreement with the observations of DeMello et al. (1987). The findings by Purvis and Cureton (1981) are also in agreement with Koltyn et al. (1991), who found that women perceived their exercise to be easier than men during swimming exercise at 90% of their best time.

Regardless of these equivocal findings, men and women typically report similar RPE values at the termination of the exercise tests irrespective of exercise mode and fitness level (Robertson et al., 2000; Faulkner et al., 2007). In addition, untrained men

and women report similar RPEs during the recovery period after running to exhaustion during a maximal exercise test (Noble, 1979).

2.2.7 Perceived exertion and disabilities

There is a strong relationship between perceived exertion and physical (PO and speed) and physiological (i.e., $\dot{V}O_2$, HR and $\dot{V}E$) indices of exercise intensity. These strong relationships are evident in able-bodied men and women (Faulkner and Eston, 2007), during leg cycling (Demura and Nagasawa, 2003) and arm cranking (Borg et al., 1087). This implies that the RPE could be used to regulate exercise intensity in able-bodied individuals. However, there are equivocal findings regarding the utility of the RPE in individuals with spinal cord injury and spinal cord disease. Some authors observed that the RPE is a good and reliable tool to gauge and prescribe exercise intensity with these populations (McLean et al., 1995; Hicks et al., 2003; Müller et al., 2004; Goosey-Tolfrey et al., 2010).

However, other authors observed that the relationship between the RPE and the physiological variables in individuals with spinal cord injury was poor (Jacobs et al., 1997; Lewis et al., 2007). These authors suggested that the RPE is not a valid method to gauge and prescribe exercise intensity for this population (Jacobs et al., 1997; Lewis et al., 2007). Alternatively, Jacobs et al. (1997) suggested that the heart rate not the RPE should be used to gauge and prescribe exercise intensity in individuals with spinal cord injury.

However, Müller et al. (2004) observed no significant difference in the reproducibility of the RPE during 5 x 1500 m exercise tests (i.e., 1 = warm up, 2 = extensive aerobic training, 3 = intensive aerobic training, 4 = training in the area of anaerobic threshold and 5 = race speed) on two different occasions. More recently, Goosey-Tolfrey et al. (2010) observed no significant differences in $\dot{V}O_2$, % $\dot{V}O_2$ peak, heart rate, %HRpeak and blood lactate between imposed exercise intensities at 50% $\dot{V}O_2$ peak (i.e., moderate) and 70% $\dot{V}O_2$ peak (i.e., vigorous) and the RPE-regulated exercise intensities.

These equivocal findings regarding the utility of the RPE in disabled individuals might be attributed to the exercise mode utilised, the level of injury at the spinal cord and, to some extent, the fitness level of the participants. The above study by Jacobs et al. (1997) tested the RPE during shuttle walking using functional neuromuscular stimulation. It is possible that this method may have affected the participants' abilities to accurately appraise their RPE in the lower limbs due to their injury. In addition, the study by Lewis et al. (2007) was based on individuals with low levels of physical activity. In their study, 10 participants had spinal injury between the 5th and 8th cervical (C) vertebra. The exercise test also utilised a discontinuous arm crank protocol. These three factors may have affected the participants' abilities to estimate their RPE accurately during arm exercise. The study by Goosey-Tolfrey et al. (2010) employed eight physically active men with injury level at or below the 4th thoracic (T) vertebra. The high fitness level, lower injury level of the participants and the exercised mode (i.e., hand cycling) utilised in their study may have facilitated a more accurate appraisal of the RPE.

2.2.8 Perceived exertion and prediction of maximal oxygen uptake

Morgan and Borg, (1976) indicated that RPE provide more accurate prediction of $\dot{V}O_2\text{max}$ than heart rate in men (i.e., 1% and 15% differences from actual $\dot{V}O_2\text{max}$, respectively). These results were replicated with women by Noble et al. (1981) (i.e., +2% and -14% differences from actual $\dot{V}O_2\text{max}$, respectively). These two studies compared means and standard deviations to assess the accuracy of predicting $\dot{V}O_2\text{max}$. A new interest in using the RPE to predict $\dot{V}O_2\text{max}$ was renewed by Eston and colleagues (Eston, 2009a; Eston et al., 2005, 2006, 2008; Faulkner and Eston, 2007; Faulkner et al., 2007; Faulkner et al., 2009; Lambrick et al., 2009). These authors used the limits of agreement (LoA) and intraclass correlation coefficient analysis (ICC) alongside the comparison of mean values to assess the accuracy of predicting $\dot{V}O_2\text{max}$.

As indicated earlier (2.2.8 Perceived exertion and prediction of maximal oxygen uptake), two procedures involving the RPE may be used to predict $\dot{V}O_2\text{max}$: i) an estimation procedure and ii) a perceptually-guided, graded exercise test. This is also known as a production procedure. The estimation procedure is a passive process in which individuals are typically asked to rate how hard an exercise bout feels to them according to a given perceptual scale (e.g., Borg 6-20 RPE scale) (Ceci and Hassmén, 1991). In contrast to the estimation procedure, the perceptually-guided, graded exercise test is an active process in which individuals are asked to produce and maintain an exercise intensity equal to a predetermined RPE level (Eston et al., 2005); typically corresponding to RPE 9, 11, 13, 15 and 17 (Eston et al., 2005, 2006, 2008; Faulkner et al., 2007). Sub-maximal $\dot{V}O_2$ values elicited during these exercise tests are regressed against the corresponding RPE values using bivariate individual linear regression analysis and then extrapolated to RPE20 values to predict $\dot{V}O_2\text{max}$.

Recently, $\dot{V}O_2\text{max}$ was predicted with reasonable accuracy by extrapolating sub-maximal RPE values to peak RPE (RPE19) or maximal RPE (RPE20) in male and female and with high- and low-fit participants using either estimation (Lambrick et al., 2009; Davies, et al., 2008; Faulkner and Eston, 2007; Faulkner et al., 2009) or production procedures (Eston et al., 2005, 2006, 2008; Faulkner et al., 2007; Faulkner et al., 2009; Morris et al., 2009, 2010). Generally speaking, there were no significant differences between measured and predicted $\dot{V}O_2\text{max}$ values from both the perceptually-guided, graded exercise test and the graded exercise test. However, the higher RPE range (i.e., RPEs before and including RPE17) provided more accurate predictions of $\dot{V}O_2\text{max}$ than the lower RPE range (i.e., RPEs before and including RPE13) as reflected by narrower limits of agreement and higher intraclass correlation coefficients (Eston et al., 2005, 2006, 2008).

It has been shown that prediction of $\dot{V}O_2\text{max}$ improved with practice as reflected by narrower LoA and higher ICC between measured and predicted $\dot{V}O_2\text{max}$ during the second trial compared to the first trial during the perceptually-guided, graded

exercise test (Eston et al., 2005, 2006, 2008; Morris et al., 2010). With regard to the estimation process, Lambrick et al. (2009) have indicated that the continuous increase in the work rate during the ramp exercise test may have facilitated an accurate estimation of perceived exertion, which in turn improved the prediction of $\dot{V}O_2\text{max}$ compared to the step-wise exercise test. These authors also indicated that utilising the ramp protocol would save time and effort in comparison to the perceptually-guided, graded exercise test and the step-wise exercise test.

2.2.9 Perceived exertion and scalar property

Horstman et al. (1979) observed a linear relationship between the RPE and time to exhaustion while walking and running at constant-load intensity corresponding to 80% $\dot{V}O_2\text{max}$. Noakes, (2004) re-plotted the RPE data from Baldwin et al. (2003) study while exercising at constant-load intensity equal to 70% $\dot{V}O_2\text{peak}$ in partial carbohydrate-depleted and carbohydrate-repleted conditions. He observed that the RPE had a linear relationship with time to exhaustion during both conditions. He also observed that the rate of change in the RPE was faster during carbohydrate-depleted compared to carbohydrate-repleted condition. However, when the RPE was regressed against the proportion of time to exhaustion, there were no significant differences in the rate of change of the RPE between the two conditions. Based on these findings, Noakes (2004, 2008) concluded that the RPE has a scalar relationship with time. In other words, he purported that the RPE increases as a proportion of time completed or proportion of time remaining to end task while exercising at constant-load to volitional exhaustion.

Eston et al. (2007) assessed whether the RPE scales with time while exercising at constant work rate corresponding to 75% $\dot{V}O_2\text{peak}$ in pre-fatigued and fresh conditions. These authors observed that the RPE increased at a significantly faster rate of change when regressed against absolute time during the pre-fatigued condition compared to the fresh condition. However, no significant differences were observed in the rate of change in the RPE when regressed against the proportion of time to

volitional exhaustion between the two conditions. These findings were also confirmed in a closed-loop exercise condition in the field. Faulkner et al. (2008) observed that the RPE increased at faster rate of change when regressed against time it took to finish a short race (i.e., 7-mile) compared to a longer race (i.e., half marathon race (13.1 mile)). However, when the RPE was regressed against the proportion of time to complete the race, no significant differences were observed in the rate of change of the RPE.

The scalar property of the RPE was also assessed during different environmental conditions. For instance, Crewe et al. (2008) observed that the RPE increased at a faster rate when exercising at a constant-load corresponding to 65% of the peak power output in a hot environment (i.e., 35°C) compared a cool environment (i.e., 15°C). However, in accordance with previous studies there was no significant difference in the rate of change of the RPE when regressed against the proportion of time to volitional exhaustion between the two conditions. This study also provides confirmatory evidence that skin and core temperatures are important antecedents for mediating the RPE in hot and cool environmental conditions.

Joseph et al. (2008) investigated the rate of change of the RPE during three different time trials (i.e., 2.5km, 5km and 10 km). These authors observed that the RPE increased at significantly higher rate of change when expressed against absolute distance during the 2.5km time trial compared to 5km and 10 km time trials and during 5km time trial compared to 10km time trial. However, when the RPE was regressed against proportion of distance covered there was no significant difference in the rate of change of the RPE between the three time trials. These authors also observed that the hypoxic condition during the 5km time trial did not affect the rate of change of the RPE as the hypoxic condition was associated with a reduction in power output.

The above observations are in agreement with the theory of teleoanticipation proposed by Ulmer (1996). This theory implies that the brain seems to set a proposed finishing point of an exercise bout and increases the RPE as a proportion of this finishing point. Adopting this theory will prevent a catastrophic disturbance to the body homeostasis and sever muscle damage (Ulmer, 1996). Supporting this theory is that

the RPE is affected by the expectations about the exercise duration with participants giving higher RPE at the same absolute time or distance during the short exercise bout compared to the longer one (Rejeski and Ribisl, 1980; Baden et al., 2004; Baden et al., 2005).

2.3 Physical disability

There is a wide range of physical disabilities such as spinal cord disabilities (i.e., paraplegia and tetraplegia), amputation, poliomyelitis, post-polio syndrome, cerebral palsy and stroke. However, the main focus of the thesis is with regard to individuals with paraplegia as a result of either spinal cord injury (SCI) or poliomyelitis. These two kinds of physical disabilities (i.e., SCI and poliomyelitis) result from an injury or an infection to the spinal cord which is one division of the central nervous system. As such, it is appropriate to review the structure of the nervous system before describing each of these disabilities in further detail.

The nervous system comprises of the central nervous system (CNS) and the peripheral nervous system (PNS). The CNS comprises of the brain and the spinal cord. All body sensations must be transferred to the CNS if they need to be interpreted and acted on (Tortora and Anagnostakos, 1987). The PNS is comprised of nerves that connect the brain and spinal cord with the receptors, muscles and glands. The PNS is divided into the afferent system (i.e., sensory neurons) and the efferent system (i.e., *motor* neurons). The afferent system consists of the nerve cells that convey information from peripheral receptors to the CNS; whereas, the efferent system consists of nerve cells that convey information from the CNS to the glands and muscles. The efferent system subdivided into somatic nervous system (SNS) and autonomic nervous system (ANS). The SNS comprised of efferent neurons that conduct impulses from CNS to skeletal muscle tissues. On the other hand, the efferent neurons of the ANS conduct impulses from the CNS to the smooth muscle tissues, glands and the heart. The ANS is subdivided into sympathetic and parasympathetic systems. Generally speaking, the sympathetic system stimulates an organ's activity and the parasympathetic decreases

an organ's activity (Tortora and Anagnostakos, 1987). The structure of the nervous system is illustrated in Figure 2.5.

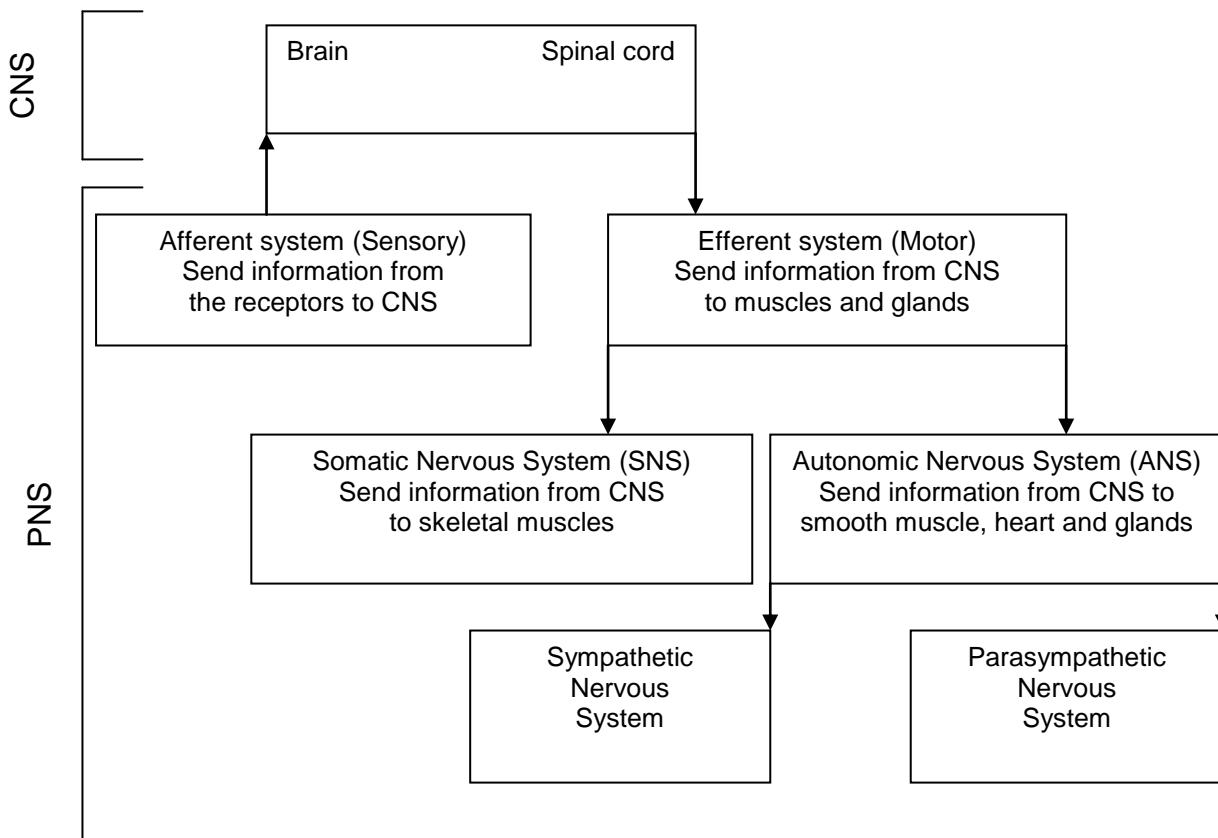


Figure 2.5: Structure of the nervous system. Note: modified from *Principles of Anatomy and Physiology* (Tortora and Anagnostakos (1987 pp. 262)).

2.3.1 Poliomyelitis (polio)

Poliomyelitis is a highly infectious viral disease that attacks and affects parts of the brain or the motor neurons (i.e., anterior horn cells that are located in the front part of the spinal cord) and in some cases causes total paralysis (Lockette and Keyes, 1994; Birk, 2009). Paralysis is a loss of the motor function and sometimes the sensory functions due to a disorder in some parts of the spinal cord which is one part of the central nervous system (Kent, 2006). Paralysis is a symptom rather than a disease and its extent depends on the level of injury or infection (Kent, 2006). The polio virus tends to affect the lower limbs more often than the upper limbs (Lockette and Keyes, 1994). Unlike spinal cord injury and spina bifida, individuals with polio do not lose sensation

in the paralyzed limbs since the virus attacks the motor neurons only (Lockette and Keyes, 1994). After vaccines were invented by Salk and Sabin in late 1950s and early 1960s the disease almost disappeared in modern countries (Birk, 2009). However, there are still a few new cases of polio occur in some of the developing countries (Howard, 2005; Birk 2009).

After about 40 years of the initial disease (i.e., polio) some individuals develop new disabilities or symptoms (Howard, 2005; Birk, 2009). These symptoms or disabilities are referred to as post-polio syndrome (Lockette and Keyes, 1994; Howard, 2005; Birk, 2009). Some of these symptoms are muscle atrophy, muscle and joints pain, fatigue with minimal activity and weakness (Howard, 2005; Birk, 2009). Post-polio syndrome is more intense and prevalent in the lower limbs (Birk, 2009). Some of these symptoms (i.e., muscle weakness, fatigue and pain) occur due to loss of the motor units as result of aging, being overweight and repetitive physical work (Birk, 2009). Being overweight and repetitive physical work will eventually lead to overloading the weakened leg muscles and overloading a smaller muscle mass, respectively (Birk, 2009).

2.3.2 Spinal cord injury (SCI)

The spinal cord is a continuation of the medulla oblongata and consists of 31 pairs of spinal nerves. These 31 pairs are divided into; 8 pairs of cervical (C) nerves, 12 pairs of thoracic (T) nerves, 5 pairs of lumbar (L) nerves, 5 pairs of sacral (S) nerves and 1 pair of coccygeal nerves (Tortora and Anagnostakos, 1987). Spinal cord injury typically causes tetraplegia or paraplegia depending on the level of lesion in the spinal cord. Injuries to the cervical segments (C1 to C8) result in tetraplegia, with impairment to the upper limbs, trunk, lower extremities and pelvic organs (e.g., bladder, bowels and sexual organs), (Figoni, 2009). Injuries to the thoracic segments result in paraplegia, with impairment to the trunk, lower limbs and pelvic organs (Figoni, 2009). Injuries to the lumbar and sacral segments (L1 to L5 and S1 to S4) result in paraplegia as well, with impairment to the lower limbs or pelvic organs or both (Figoni, 2009).

The degree of impairment depends on the neurological level and completeness of injury (Figoni, 2009). In other words, the higher the level of injury the more muscles are paralysed. With regard to the completeness of injury, this can be classified as: i) complete injury or ii) incomplete injury (Jacobs and Nash, 2004). Complete injury means no sensory or motor function is preserved in the lowest sacral segment (Jacobs and Nash, 2004). Incomplete injury means partial preservation of motor and/or sensory functions below the level of injury and including the lowest sacral vertebra (Jacobs and Nash, 2004).

Most individuals with spinal cord injury acquire their disability from traumatic injury to the spinal cord (Figoni, 2009; Hopman, 1994). These traumatic injuries usually result from motor vehicle accidents, falls, diving, violence, infection or tumor of the spinal cord and surgical complications (Hopman, 1994; Figoni, 2009). In addition, some disabilities of the spinal cord result from spina bifida (SB). Spina bifida is a congenital disability which results from incomplete development and closure of one or more of the posterior vertebral arches and cause spinal cord damage (Lockette and Keyes, 1994; Figoni, 2009). Spina bifida is most common in the lower thoracic, lumber and sacral segments of the spinal cord and individuals with spina bifida lose motor and/or sensory functions partially or totally below the affected segment similar to those with spinal cord injury (Lockette and Keyes, 1994).

2.3.2.1 Effect of spinal cord injury on muscles, bones, heart, the circulation system and the pulmonary system

Individuals with spinal cord injury usually experience muscle atrophy below the lesion level due to loss of motor innervation to these muscles (Gordon and Mao, 1994; Hopman et al., 1997). This muscular atrophy is reflected by a reduction in the size and/or number of muscle fibres (Martin et al., 1992; Gordon and Mao, 1994). These individuals also undergo some transformation of muscle fibres from type I (slow-twitch) to type II (fast-twitch), (Janssen and Hopman, 2005). These changes in fibre type are associated with some metabolic changes such as a decreased mitochondrial content and a decreased oxidative enzyme activity (Martin et al., 1992; Janssen and Hopman,

2005). In this respect, Martin et al. (1992) observed a significantly reduced oxidative enzyme activity (i.e., succinate dehydrogenase (SDH)) in individuals with SCI compared to their able-bodied counterparts. These changes in muscle fibres and metabolic profile can be attributed to decreased neuromuscular activity, decreased mechanical load (Gordon and Mao, 1994; Janssen and Homan, 2005), decreased oxygen demand, decreased stretch and possibly hormonal changes (Janssen and Homan, 2005).

Osteoporosis, characterised by low bone mineral density (ASCM, 2010), is common among individuals with spinal cord injury in the paralysed extremities, mainly as a result of adopting a sedentary life style (Garland et al., 1992; Lockette and Keyes, 1994; Garland and Adkins, 2001; Janssen and Hopman, 2005). As such, these individuals are at higher risk of bone fracture (Dauty et al., 2000). Even in individuals with high lesions, spasticity does not help in maintaining bone health and preventing bone problems (Lockette and Keyes, 1994). Maintaining bone health and preventing bone problems can be attained through volitional contractions only (Lockette and Keyes, 1994). Therefore, more attention and care are needed when transferring these individuals from wheelchairs into cars or from wheelchairs to other devices to do exercise tests. Similarly, more attention is needed when performing walking activities using functional neuromuscular stimulation as this may result in bone fractures in individuals who have osteoporosis.

Individuals with spinal cord injury exhibit a reduction in heart size, especially the left ventricle, compared to their able-bodied counterparts. That was particularly evident in individuals with tetraplegia and sedentary paraplegic individuals (Kessler et al., 1986; Huonker et al., 1998). These individuals also experience some alterations in blood vessels in the paralysed legs such as a decreased the diameter of the common femoral artery (Nash et al., 1996; Huonker et al., 1998). These changes might be attributed to the decreased oxygen demand in the paralysed legs (Janssen and Hopman, 2005). In contrast, it has been shown that arm exercise increased the diameter of the brachial artery in paraplegic individuals (Shenberger et al., 1990). Veins also undergo some alterations in these individuals such as a decreased in diameter, reduced venous

capacity and increased venous outflow resistance compared to their able-bodied counterparts (Frieden et al., 1987; Janssen and Hopman, 2005). These alterations in the circulatory system in individuals with spinal cord injury may explain the lower stroke volume during sub-maximal arm exercise which is compensated by a higher heart rate (Hjeltnes, 1977; Huonker et al., 1998; Janssen and Hopman, 2005). It has also been shown that lower stroke volume limits both maximal cardiac output and peak oxygen uptake in paraplegic individuals (Hjeltnes, 1977; Huonker et al., 1998; Janssen and Hopman, 2005).

With regard to the respiratory system, individuals with spinal cord injury at or below C4 can stay alive without artificial breathing support (Lockette and Keyes, 1994). Individuals with tetraplegia have a reduced vital capacity, the quantity of air which can be moved from the lungs from full inspiration to full expiration (Eston and Romer, 2009), (Forner, 1980; Hopman et al., 1997; Baydur et al., 2001), which might be attributed to reduced expiratory reserve volume and elevated residual volume (Janssen and Hopman, 2005). These individuals also have a reduced maximal expiratory rate (Janssen and Hopman, 2005). Furthermore, these individuals exhibit low maximal strength and low endurance capacity of the respiratory muscles (Hopman, 1997). It can be concluded that the respiratory system of paraplegic individuals is not as affected as in tetraplegic individuals. This is most likely attributed to the lesion level.

2.3.2.2 Spinal cord injury and exercise

Individuals with spinal cord injury should engage in exercise programmes which involve arm exercise and combined arm and leg exercise. Obviously, exercise programmes are more important for individuals with spinal cord injury than able-bodied individuals since it has been indicated that individuals with spinal cord injury are: i) generally less active and tend to adopt a sedentary lifestyle after having their lesions (Dearwater et al., 1986; Davis, 1993; Collins et al., 2010), ii) typically young and physically active when they had the lesion (Jacobs and Nash, 2004), iii) sedentary which will lead to some health complications such as obesity, diabetes and coronary heart disease and will accelerate aging (Zwieren and Bar-Or, 1975; Hooker and Wells,

1989; Hopman, 1994). It has also been indicated that cardiovascular complications are responsible for the highest cause of death (25%) in individuals with SCI followed by respiratory dysfunction (21%), committing a suicide (21%) and urinary tract disease (14%), (Le and Price, 1982). Furthermore, depression is common among these individuals (Bombardier et al., 2004; Figoni, 2009; Birk, 2009), which may in turn lead them to commit suicide. As such, participation in exercise programmes may play a major role in decreasing stress and depression (Hicks et al., 2003) which in turn may protect these individuals from committing suicide.

As mentioned above, individuals with spinal cord disabilities generally have a sedentary life style (Dearwater et al., 1986; Davis, 1993; Collins et al., 2010). In addition, depression is common among individuals with spinal cord disabilities (Bombardier et al., 2004; Figoni, 2009; Birk, 2009). Therefore, exercise adherence must be improved by using suitable methods to gauge and prescribe exercise intensity. Although heart rate is the most widely used means to control exercise intensity, individuals with high SCI lesions have attenuated heart rate with maximal heart rate (HRmax) between 120 b-min^{-1} to 130 b-min^{-1} due to the impaired sympathetic signals below the lesion level (Hopman, 1994; Janssen and Homan, 2005). Furthermore, even for able-bodied participants arm exercise usually elicits a lower HRpeak, $11 \text{ b}\cdot\text{min}^{-1}$ in average, compared to leg cycling (Stenberg et al., 1967; Franklin, 1985). That means, if the traditional equation ($\text{HRmax} = 220 - \text{age}$) is used to predict HRmax, at a given percentage of HRmax arms will be exercising at higher percentage of HRmax compared to legs. To the best of our knowledge, there is no equation to predict HRmax during arm exercise for able-bodied and those with spinal cord injury (i.e., at T6 and below). Therefore, there is a need for an equation to predict HRmax during arm exercise for these populations.

The proportions of heart rate reserve (HRR), HRmax, $\dot{V}\text{O}_2\text{max}$ and POmax are usually used to gauge and prescribe exercise intensity in individuals with spinal cord injury (Dicarlo, 1988; Hooker and Wells, 1989; McLean et al., 1995; Hicks et al., 2003). The rating of perceived exertion is also one of the methods which can be used to

regulate exercise intensity in individuals with spinal cord injury (McLean et al., 1995; Hicks et al., 2003) which in turn may improve exercise adherence. Parfitt et al. (2000) have indicated that participants exercised at higher exercise intensity during preferred session (71% $\dot{V}O_{2\text{max}}$) compared to prescribed session (65% $\dot{V}O_{2\text{max}}$). However, there were no differences in the RPE between the two sessions. This may indicate a positive perception during preferred session compared to prescribed one since they worked at higher intensity and reporting similar RPE. In addition, participants usually exercise at ~ 50% $\dot{V}O_{2\text{max}}$ or POmax when they were asked to exercise at RPE13 (Parfitt et al., 1996; Faulkner and Eston, 2007; Lambrick et al., 2009). This exercise intensity is considered safe and efficient since it is equal to the recommended training threshold which can bring about some adaptations to the cardiorespiratory system (Parfitt et al., 1996; ACSM, 2010).

2.3.2.3 Spinal cord injury and arm exercise

Arm exercise is an appropriate mode of exercise testing and prescription for individuals with spinal cord injury (Franklin, 1985; Hopman, 1994). Arm exercise is less efficient compared to leg exercise (Eston and Brodie, 1986; Sawka, 1986). Arm exercise also elicits lower peak values for heart rate, $\dot{V}O_2$, \dot{V}_E and PO compared to leg cycling (Sawka, 1986; Aminoff et al., 1996). Although arm crank ergometer is the most used device for upper body exercise testing (Sawka, 1986), its lack of specificity for wheelchair propulsion is considered as a limitation for its usefulness (Sawka, 1986; Jacobs and Nash, 2004). Therefore, it seems reasonable to compare the physiological responses between arm cranking and wheelchair propulsion.

2.3.2.3.1 Arm cranking vs. wheelchair propulsion

Individuals respond to exercise differently based on the ergometer utilised during exercise. For example, for the same individual leg cycling elicits a lower $\dot{V}O_{2\text{max}}$ compared to running on treadmill (Åstrand et al., 2003). Arm ergometry and wheelchair propulsion are the most used ergometers for exercise training and testing with paraplegic individuals (Franklin, 1985; Hopman, 1994). Therefore, some authors

were interested in assessing whether there is a difference in the physiological responses during exercise between these two ergometers. For instance, Gass and Camp (1984) observed a significantly higher peak values for oxygen uptake, $\dot{V}CO_2$, \dot{V}_E and heart rate during wheelchair propulsion exercise compared to arm cranking ergometry in ten physically active paraplegic men. In contrast, Glaser et al. (1980) observed significantly higher peak values for power output, heart rate and blood lactate concentration during arm cranking ergometry compared to wheelchair ergometer in six wheelchair-dependent participants and ten able-bodied participants.

Wicks et al. (1983) found no significant difference between the two modes of exercise in peak values for heart rate and $\dot{V}O_2$ in tetraplegic and paraplegic male participants. In their study, paraplegic women achieved higher $\dot{V}O_2$ peak during arm cranking ergometry compared to wheelchair propulsion exercise. In addition, in their study, all participants achieved a significantly higher POpeak during arm cranking ergometry compared to wheelchair ergometer. Gass and Camp (1984) indicated that the higher physiological responses during wheelchair propulsion compared to arm cracking ergometer are attributed to the fact that more muscle mass is engaged during wheelchair propulsion compared to arm cranking ergometry. This interpretation is in accordance with previous research which compared arm cranking versus leg cycling in able-bodied individuals (Bergh et al., 1976; Davis et al., 1976; Franklin et al., 1983; Vander et al., 1984; Eston and Brodie, 1986; Aminoff et al., 1996).

It has been indicated that the arm crank ergometer is the most commonly used device for exercise testing in individuals with spinal cord injury (Hopman, 1994; Jacobs and Nash, 2004). The arm crank ergometer is also available in rehabilitation and gym settings and the work rate can be standardized and controlled (Jacobs and Nash, 2004). These features are considered advantageous especially if direct comparison between able-bodied and paraplegic individuals is needed. In addition, it has been indicated that wheelchair propulsion is less efficient (i.e., 2-10% lower) compared to arm crank ergometer (Sawka et al., 1980; Coutts et al., 1983; Hopman et al, 1995).

This might be attributed to the fact that: 1) wheelchair propulsion involves more isometric exercise to stabilize the torso when applying the forces to the hand rims compared to arm cranking (Lockette and Keyes, 1994); 2) transmission of forces is more efficient using a handle compared to the hand rim (Lockette and Keyes, 1994); 3) there is less synchronization between neural pathways and arm movements during wheelchair propulsion compared to arm cranking (Lockette and Keyes, 1994).

At sub-maximal power outputs of 5, 15, 25 and 34 W Sawka et al. (1980) observed lower values for $\dot{V}O_2$, HR, \dot{V}_E , systolic blood pressure and rate pressure product during arm cranking compared to wheelchair propulsion in seven wheelchair-dependent persons and ten able-bodied participants. The higher sub-maximal $\dot{V}O_2$ values during wheelchair propulsion confirmed its lower efficiency compared to arm crank ergometer. These authors indicated that the higher sub-maximal $\dot{V}O_2$ values during wheelchair propulsion compared to arm cranking might be attributed to the fact that arm cranking includes a constant pull and push movements. However, wheelchair propulsion is an intermittent activity in nature. In other words, force is applied during the forward arm swing only and therefore the back swing of the arms leads to some energy loss during wheelchair propulsion (Vanlandewijck et al., 1994). Regardless of these advantages of arm cranking compared to wheelchair propulsion, the lack of task specificity of arm cranking ergometry is considered as a limitation for its usefulness with these populations (Hopman, 1994; Lockette and Keyes, 1994; Jacobs and Nash, 2004).

2.3.2.3.2 Responses to sub-maximal arm exercise

Individuals with SCI have a lower stroke volume which is compensated by higher heart rate during sub-maximal arm exercise compared to able-bodied individuals (Hjeltnes, 1977; Jehl et al., 1991; Hopman et al., 1993; Hopman, 1994). Hopman et al. (1993) observed a lower cardiac output at 50%, 70% and 80% of POmax in 11 paraplegic men with lesions at T7 and below compared a control group of 5 wheelchair-dependent men. These differences in sub-maximal exercise responses in

paraplegic compared to able-bodied individuals are attributed to the impaired redistribution of blood below the lesion level due to the lack of sympathetic vasoconstriction and due to the inactive muscle pumping mechanism as a result of the lack of motor innervation to the lower limbs (Hopman, 1994; Janssen and Hopman, 2005). On the basis of Frank-Starling mechanism, these factors reduce venous return to the heart and consequently lower stroke volume at a given exercise intensity will be present in individuals with spinal cord injury compared to their able-bodied counterparts.

2.3.2.3.3 Responses to maximal arm exercise

Individuals with tetraplegia have lower peak values for PO, $\dot{V}O_2$, \dot{V}_E and heart rate compared to those with paraplegia (Coutts et al., 1983; Wicks et al., 1983; Figoni, 1993). It has been indicated that tetraplegic individuals have HRmax ranges between 120 $b.\text{min}^{-1}$ and 130 $b.\text{min}^{-1}$ (Figoni, 1993; Janssen and Hopman, 2005). These differences between tetraplegic and paraplegic individuals are most likely attributed to the higher level of injury in tetraplegic individuals and consequently more muscles are paralysed compared to those with paraplegia (Coutts et al., 1983, 1985).

It should be borne in mind that tetraplegics and paraplegic individuals with high lesions are at higher risk of hypotension (drop in blood pressure) during exercise and during orthostatic posture due to the loss of sympathetic innervation to the blood vessels in the lower limbs (Lockette and Keyes, 1994). That is, during exercise vasodilation occurs in the upper limbs but there is no concomitant vasoconstriction occurs in the lower limbs which will cause hypotension during exercise. Similarly, if these individuals stand for a period of time blood will be pooling in the lower limbs which in turn will cause orthostatic hypotension. People who deliver exercise to these individuals should bear in mind this point and how to deal with it if it occurs. It has been suggested that if hypotension occurs put the wheelchair in a recumbent position or elevate the participants' legs while he or she is placed on his or her back in order to increase the venous return to the heart (Lockette and Keyes, 1994).

These individuals also have impaired thermoregulation system due to their impaired autonomic nervous system (Sawka et al., 1989). The degree of impairment is dependent upon the level and the completeness of injury. Therefore, these individuals are not able to regulate body temperature by heat loss via vasomotor (i.e., vasodilation and vasoconstriction of blood vessels) and sudomotor (i.e., sweating) compared to their able-bodied counterparts (Sawka et al., 1989). For example, individuals with SCI at C7 to S1 were not able to regulate their core temperature when exposure to cold (i.e., 15 °C) and hot (i.e., 40 °C) ambient temperatures compared to able-bodied participants (Sawka et al., 1989). It is worth mentioning that people who work with these individuals should bear in mind this point especially when exercising in cold and hot ambient temperatures. If exercise to be performed in hot ambient temperatures cold clothes should be brought to cool participants down during exercise in order to avoid hyperthermia from occurring. Similarly, if exercise to be performed in cold ambient temperatures warm clothes should be brought to warm the participants during exercise in order to avoid hypothermia from occurring.

Able-bodied individuals usually elicit higher peak values for PO, $\dot{V}O_2$, \dot{V}_E and cardiac output compared to their matched (i.e., similar age and physical activity) paraplegic counterparts (Zwiren and Bar-Or, 1975; Jehl et al., 1991; Hopman et al., 1992; Hooker et al., 1993). These differences between able-bodied and paraplegic individuals are mainly attributed to: 1) the smaller muscle mass activated during exercise in paraplegic individuals compared to their able-bodied counterparts (Hopman et al., 1992); 2) able-bodied participants are able to use the torso and their lower limbs for stabilization and as a fulcrum from which to push (Hopman, 1994; Janssen and Hopman, 2005); 3) the contribution of the trunk is higher during maximal exercise test in able-bodied participants compared to those with paraplegia which might in turn help able-bodied individuals to achieve higher peak values for power output and oxygen uptake.

2.3.3 Mechanical efficiency and modality of exercise

Mechanical efficiency is the ratio between work output and work input (Kent, 2006). It has been shown that arm cranking exercise is less efficient (i.e., 2-4%) compared to leg cycling and combined arm and leg exercise (Eston and Brodie, 1986). This may be attributed to the fact that more muscle groups are recruited to stabilise the torso which consume more energy and does not contribute to the external work output (Eston and Brodie, 1986; McArdle et al., 2007). Gripping during arm cranking exercise is another example of recruiting additional muscle groups which consume more energy and does not contribute to the external work output.

It has also been indicated that arm cranking exercise is more efficient (i.e., 2-10% higher) compared to wheelchair propulsion (Sawka, 1986; Hopman et al., 1995). This might be attributed to the fact that arm cranking exercise is asynchronous exercise (i.e., one arm pulls and the other arm pushes and vice versa). However, wheelchair propulsion is a synchronous exercise (i.e., both arms push the hand rim of the wheelchair simultaneously). As force can be applied during the forward arm swing during wheelchair propulsion, this means that the backward swing of the arms result in some energy loss (Sawka et al., 1980; Vanlandewijck et al., 1994). There is a substantial body of research which has assessed mechanical efficiency during asynchronous and synchronous exercise (e.g., Hopman et al., 1995; Goosey-Tolfrey and Kirk, 2003; Lenton et al., 2008). Hopman et al. (1995) observed lower mechanical efficiency while exercising at sub-maximal power output equal to 30W during synchronous (similar to wheelchair movement) exercise compared to asynchronous exercise during arm cranking exercise in ten able-bodied participants. However, these authors did not observe significant differences between the two strategies of exercises at 60W and 90W (Figure 2.6).

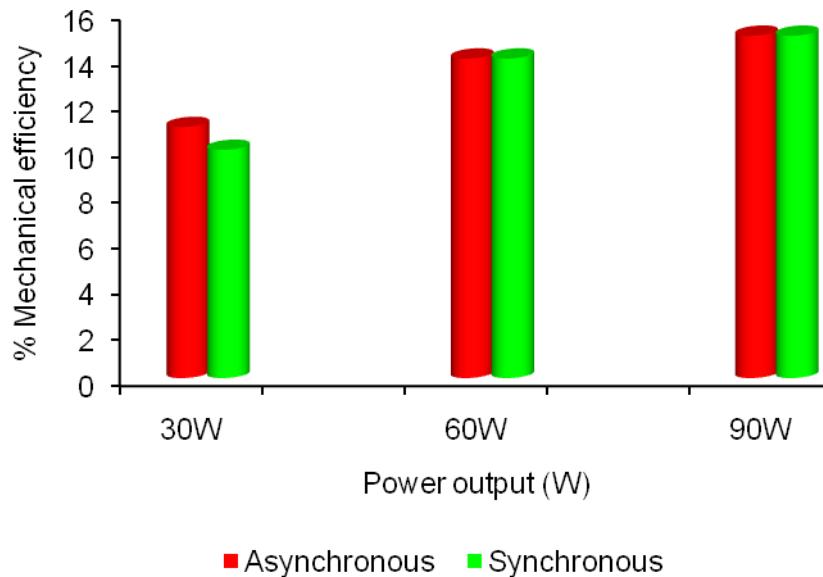


Figure 2.6: Mechaincal efficiency duirng synchronous and asynchronous exercise.
Note: adapted from Hopman et al. (1995). Physiological responses to asynchronous and synchronous arm-cranking exercise. *European Journal of Applied Physiology*, **72**, 111-114.

In a study which compared synchronous vs. asynchronous strategies at two different pushing frequencies (i.e., 40 and 70 push/min) during wheelchair propulsion in twelve able-bodied participants, Goosey-Tolfrey and Kirk, (2003) observed that synchronous exercise at a pushing frequency of 40push/min is the most efficient condition compared to the other conditions. These authors also observed lower values for overall, peripheral and central RPE during synchronous strategy using 40 push/min compared to 70 push/min. These findings are surprising as it has been shown that RPE values decrease with the increase in pedal cadence during leg cycling exercise (Robertson et al., 1979a). However, in accordance with previous research (Ekblom and Goldbarg, 1971; Demura and Nagasawa, 2003; Faulkner and Eston, 2007) peripheral RPE was higher compared to central and overall RPE during all conditions. These authors also did not observe significant differences in overall, peripheral and central RPE between synchronous and asynchronous strategies, regardless of pushing frequencies. Lenton et al. (2008) also did not observe significant difference in overall, peripheral and central RPE between synchronous and asynchronous strategies while exercising at 60%, 80%, 100%, 120% and 140% of freely chosen frequency.

2.4 Purpose of the studies

It is clear that the study of perceived exertion is an important area of study in persons with paraplegia. To date, there are a limited number of studies on the use and efficacy of perceived exertion in persons with spinal cord injury and/or disease. The findings from these studies are also equivocal. Recent advances in the study of perceived exertion show that it may be used to predict maximal functional capacity in able-bodied healthy, sedentary and obese persons, when applied in both *estimation* and *production* protocols. Other recent studies show that the RPE is also related to the time remaining to volitional exhaustion in able-bodied individuals. At the present time, our knowledge of the validity and usefulness of the RPE in paraplegic individuals remains limited. The purpose of the studies which follow are therefore to assess: i) the strength of the relationship between the RPE and physical and physiological markers of exercise intensity during arm cranking exercise in able-bodied and paraplegic individuals; ii) the accuracy of predicting peak oxygen uptake ($\dot{V}O_2\text{peak}$) from submaximal RPE and $\dot{V}O_2$ values when extrapolated to RPE of 20 (maximal RPE) using both *estimation* and *production* procedures in able-bodied and paraplegic individuals; iii) the scalar property of the RPE during arm cranking exercise while exercising at two different constant-load exercise intensities in able-bodied and paraplegic individuals.

Chapter 3

Common methods

The aim of this chapter is to summarise the common methods used in the six studies of the thesis.

3.1 Measurement of height and body mass (for all the studies)

On the first visit, all participants (i.e., able-bodied and paraplegic) provided written informed consent and were measured for body mass (SECA, Hamburg, Germany), height and blood pressure (Accoson, London, England). For paraplegic individuals, body mass was measured while seated and height was measured in the supine position to the nearest 0.1 cm with a tape measure.

3.2 Borg 6-20 RPE Scale

The Borg 6-20 RPE Scale is the most widely used scale to assess the perception of effort during exercise, regardless of gender, physical activity level (i.e., sedentary, physically active and athletes) and age (i.e., young and adults). Therefore, the Borg 6-20 RPE Scale (Table 2.1) was used to assess the perception of effort during all the studies. The scale was used in all *estimation* and *production* procedures. The *estimation* procedure is a *passive* process in which an individual indicates how 'hard' or 'easy' an exercise feels (Ceci and Hassmén, 1991). The *production* procedure is an *active* process in which an individual is asked to produce and maintain an exercise intensity equal to a given RPE (Smutok et al., 1980; Eston et al., 1987). Recently Eston et al. (2005) have applied the *production* procedure in the form of a perceptually-guided, graded exercise test. In this exercise test, participants are usually asked to exercise for 3 minutes at each of these exercise intensities (i.e., RPE 9, 11, 13, 15 and 17). The aim of the exercise test is to predict maximal oxygen uptake by extrapolation of the perceptually-guided sub-maximal oxygen uptake values to the theoretical maximal RPE (RPE20).

In all *estimation* procedures participants were familiarized with the Borg 6-20 RPE (Table 2.1) Scale and were given standardised instructions on how to report their overall feelings of exertion (*RPEo*, i.e., a rating of *overall* exertion which takes into

account how hard breathing feels, how fatigued the arms feel and how hot the participant feels) and their feelings of exertion in the arms only (*RPE_p*, i.e., how fatigued the arms feels) prior to each exercise test (Borg, 1998). Any questions concerning the scale were answered before exercise commenced. Participants reported their RPEo and RPE_p at the completion of the exercise tests and in the remaining 20 s of each minute and each stage during the ramp exercise test and the graded exercise test, respectively. However, during the constant-load exercise tests both overall RPE and peripheral RPE were collected at random times in order not to give the participants indicator about the time had elapsed. Where both overall RPE and peripheral RPE were collected, for all occasions overall RPE was collected first.

3.3 Gas analysis

Study 1 & 2

On-line respiratory gas analysis occurred throughout each exercise test via a breath-by-breath automatic gas calibrator system (Quark, PFT 2 Ergo, Cosmed, Rome, Italy). Expired air was collected continuously using a facemask to allow participants to verbally communicate to the experimenter (i.e., when reporting their RPE). The system was calibrated (gas, pressure) prior to each exercise test in accordance with manufacturer's guidelines. A wireless chest strap telemetry system (Polar Electro T31, Kempele, Finland) continuously recorded the heart rate during each exercise test. All physiological ($\dot{V}O_2$, carbon dioxide ($\dot{V}CO_2$), \dot{V}_E , respiratory exchange ratio (RER) and heart rate) and physical (PO and time) outputs were concealed from the participants' sight during the exercise tests.

Study 3, 4, 5a & 6

On-line respiratory gas analysis occurred every 10 s throughout each exercise test via an automatic gas calibrator system (Cortex Metalyzer II, Biophysik, Leipzig, Germany). Expired air was collected through a low resistance Hans-Rudolph facemask to allow the participants to report their RPE. The system was calibrated prior to each exercise test using a 3-L syringe for volume calibration and the ambient air measure for gas calibration as recommended by the manufacturer's guidelines. The heart rate was

recorded continuously during each exercise test using a wireless chest strap telemetry system (Polar Elector T31; Kempele, Finland).

3.4 Arm ergometry

Study 1 & 2

Both exercise protocols (i.e., leg cycling and arm cranking) were performed on the same Lode arm and leg ergometer (Lode, B.V. Medical Technology, Groningen, Netherlands). The handles were replaced with pedals for leg cycling to be performed and pedals were replaced with handles for arm cranking to be performed. During arm cranking exercise test the midpoint of the ergometry was set at shoulder level and the distance was set to allow a slight bend in the elbow when the arm was extended (Figure 3.1). The resistance on the ergometer was manipulated using the *Lode Workload Programmer*, accurate to ± 1 W, which was independent of pedal cadence.



Figure 3.1: An example showing how the height of the arm crank and the distance between the arm crank and the participant were set. Note: this photo was used with written permission from the participant.

Study 3, 4, 5a, 5b & 6

All exercise tests were performed on the same Lode arm ergometer (Lode, B.V. Medical Technology, Groningen, the Netherlands). The ergometer was stabilised on a table and a Bidex chair (Biodex Medical Systems, New York, USA) was used during all exercise tests for both able-bodied and paraplegic individuals (Figure 3.2). This chair has the advantage of moving forward, backward and upward. For able-bodied participants, straps were used to stabilise the legs and to minimise their contribution during the exercise tests. The midpoint of the ergometer was set at shoulder level and the distance was set to allow a slight flexion in the elbow when the arm was extended. The resistance on the ergometer was manipulated using the *Lode Workload Programmer*, accurate to ± 1 W, which was independent of pedal cadence.



Figure 3.2: An example showing the Bidex chair and the arm crank ergometer. Note: this photo was used with written permission from the participant.

3.5 Ramp exercise test

Leg cycling ramp exercise test (study 1)

The test commenced with participants performing 4 minutes warm-up at 0 W. Pilot research was used to identify: i) a suitable cadence, and ii) an increment in power

output that would enable $\dot{V}O_2$ peak to be ascertained within approximately 8 to 12-min, as recommended by the American College of Sports Medicine (ACSM, 2010). The increments in power output were $24 \text{ W} \cdot \text{min}^{-1}$ and $12 \text{ W} \cdot \text{min}^{-1}$ for men and women, respectively. During the last 20 seconds (s) of every minute of the ramp exercise tests, and at the completion of the exercise test, participant's estimated their overall RPE. Following completion of the test, participants were encouraged to pedal against a light resistance (0 W) and perform some stretching exercises to aid recovery. Based upon previous research (Eston and Williams, 1986; Dunbar et al. 1994; Demura and Nagasawa, 2003), participants maintained a cadence of 60 revolutions per minute (rpm) during the leg cycling exercise test.

Criteria of terminating the exercise test were:

1. A plateau in oxygen uptake (i.e., an increase of less than $2 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ while exercise intensity is increasing (Cooke, 2009)).
2. Volitional exhaustion (Faria et al., 2005; Cooke, 2009).
3. If participants were not able to maintain the required pedal cadence (i.e., if the pedal cadence dropped by 5 rpm for a consecutive 20 s from the required pedal cadence).
4. RER values of 1.15 and above (Cooke, 2009).
5. Reporting an RPE of 19 or 20 at the termination of the exercise test (Cooke, 2009).
6. A post exercise blood lactate concentration of 8 mmol^{-1} or more retrospectively confirmed that participant achieved their peak functional capacity (Cooke, 2009).

Arm cranking ramp exercise test (study 1 & 2)

Following 4 minutes warm-up at 0 W, the increments in power output were $15 \text{ W} \cdot \text{min}^{-1}$ and $6 \text{ W} \cdot \text{min}^{-1}$ for able-bodied men and women, respectively. A $9 \text{ W} \cdot \text{min}^{-1}$ and $6 \text{ W} \cdot \text{min}^{-1}$ increments in power output were more appropriate for the paraplegic men and women, respectively. In accordance with previous research (Schwade et al., 1977; Raymond et al., 1997; Kang et al., 1999), participants maintained a cadence of 50 rpm during the arm cranking exercise test. Criteria of termination the exercise test and the

ensuing recovery period, was identical to that utilised during the leg cycling exercise test.

Arm cranking ramp exercise test (study 3 & 6)

After warming up for 3 min at 0 W, the exercise test started at 0 W and was increased by 1 W every 4 s ($15 \text{ W} \cdot \text{min}^{-1}$) until volitional exhaustion for both able-bodied and persons with paraplegia (Figure 3.3). During the last 20 s of every minute and at the completion of the exercise test, participants estimated their overall and peripheral RPE. The aim of this exercise test was to establish the peak functional capacity and to determine two different constant-load exercise intensities equal to 50% and 70% delta ' Δ ' (i.e., 50% and 70% of the difference between the gas exchange threshold and peak work rate). All physiological (i.e., HR, $\dot{V}\text{O}_2$, \dot{V}_E and Respiratory Exchange Ratio (RER)), physical (PO and time) variables were kept out of the participants' sight during all exercise tests. Participants were verbally encouraged to continue exercising and to push themselves to the upper limit during exercise. Criteria of termination the exercise test and the ensuing recovery period, was identical to that utilised during study 1 and 2 except that blood lactate concentration was not measured in these studies. In accordance with previous research (Borg et al., 1987; Aminoff et al., 1996; Muraki et al., 2004), participants were asked to maintain the pedal cadence at 60 rpm during the exercise tests. For all participants (i.e., able-bodied and paraplegic) arm ergometry was not a familiar mode of exercise training.

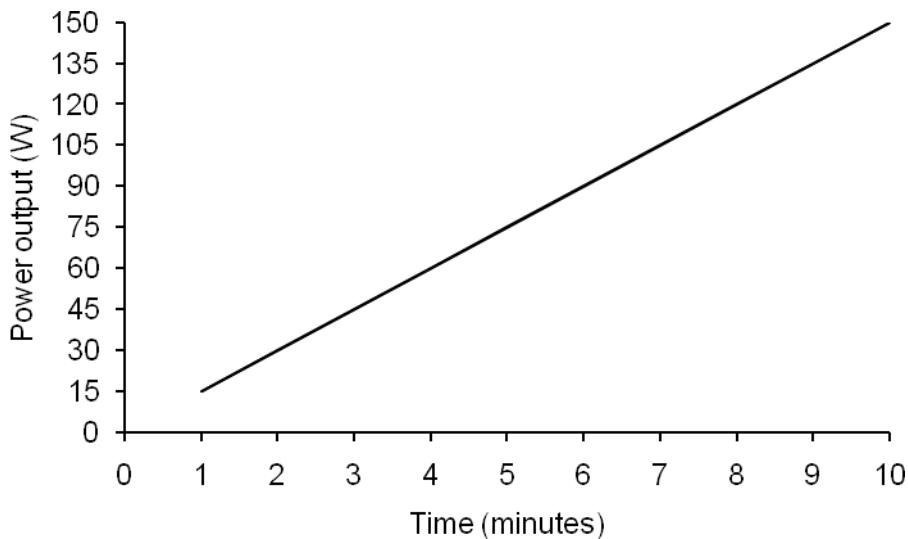


Figure 3.3: The ramp exercise test for both groups

3.6 Graded exercise test (study 3, 4, 5a, 5b & 6)

After warming up for 3 min at 0 W, the exercise test started at 30 W and increased by 15 every 2 minutes until volitional exhaustion for both able-bodied and persons with paraplegia (Figure 3.4). In the remaining 20 s of each stage and at the termination of the exercise test, participants were asked to estimate their overall and peripheral RPE. The aim of this exercise test was to establish the peak functional capacity and to assess whether there was a difference in the peak values of heart rate, $\dot{V}O_2$, $\dot{V}E$ and PO between the ramp exercise test and the graded exercise test. All physiological (i.e., HR, $\dot{V}O_2$, $\dot{V}E$ and RER), physical (PO and time) variables were kept out of the participants' sight during all exercise tests. If the participant completed one minute at least during the last stage, that was considered to be the PPeak and the highest mean rate of oxygen uptake recorded during the last 20 s of each stage was considered as the $\dot{V}O_2$ peak. Participants were verbally encouraged to continue exercising and to push themselves to the upper limit during exercise. Participants were asked to maintain the pedal cadence at 60 rpm during the exercise tests. Criteria of terminating the exercise test and the ensuing recovery period, was identical to that utilised during study 1 and 2 except that blood lactate concentration was not measured in these studies.

In study 5b expired air was not analysed. Therefore, criteria of termination the exercise test were volitional exhaustion and if the pedal cadence drop by 5 rpm for a consecutive 20 s from the required pedal cadence (i.e., 60 rpm).

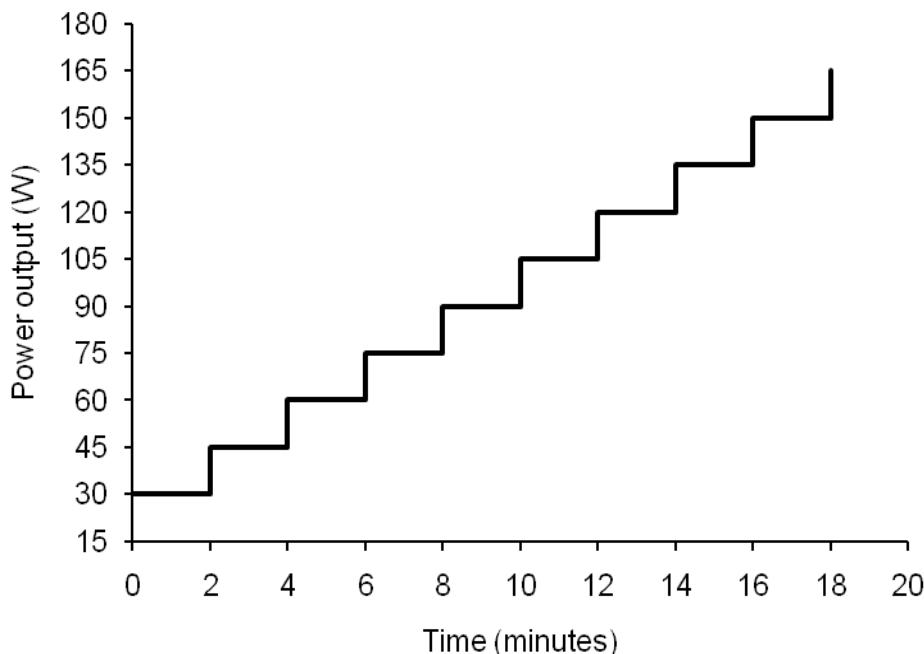


Figure 3.4: The graded exercise test exercise test for both groups

3.7 Perceptually-guided, graded exercise test (study 4 & 5b)

The *production* mode of the RPE was used in the form of a perceptually-guided, graded exercise test. In accordance with previous research (Eston et al., 2005, 2006, 2008, Faulkner et al., 2007) and to allow enough time for heart rate and oxygen uptake to reach a steady-state, participants (i.e., able-bodied and paraplegic) were asked to exercise for 3 minutes at each of these RPEs on the Borg 6-20 RPE Scale (i.e., RPE 9, 11, 13, 15 and 17). Increments of 10 W were used to increase the work rate between the prescribed RPE levels. If more resistance was needed, 5 and 3 W increments were used until the target RPE level was achieved. Participants were asked to feel free to ask the experimenter to amend the exercise intensity at any point during the 3-min stages to equate to their feeling of exertion at the prescribed RPE during each stage. As indicated earlier, the aim of this exercise test was to predict peak

functional capacity ($\dot{V}O_2\text{peak}$) by extrapolating sub-maximal $\dot{V}O_2$ and RPE values to RPE20 for able-bodied and paraplegic individuals (study 4). The second aim of this exercise test was to predict POpeak by extrapolating sub-maximal power output and RPE values to RPE20 for able-bodied participants (study 5b). Figure 3.5 is an example demonstrating the linear relationship between power outputs (W) achieved during arm cranking perceptually-guided, graded exercise test and RPE of 9, 11, 13, 15 and 17.

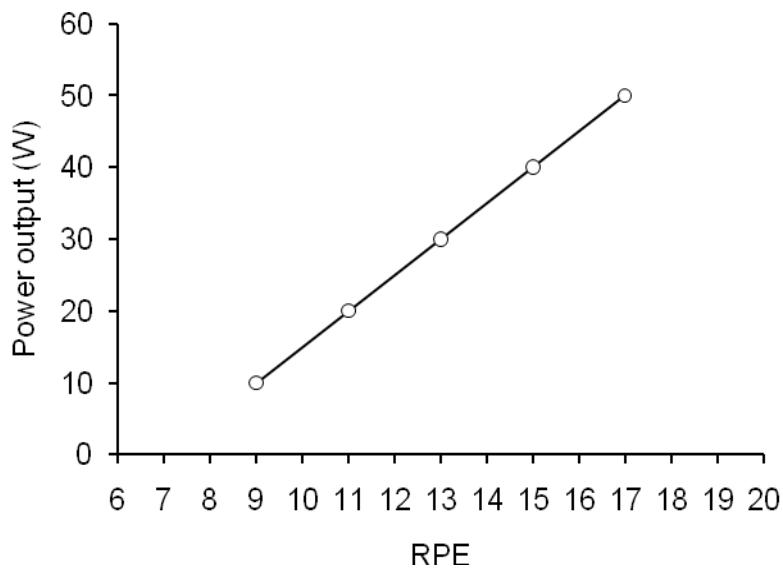


Figure 3.5: Example of the linear relationship between power output (W) and RPEs of 9, 11, 13, 15 and 17 during arm cranking exercise

3.8 Determination of the gas exchange threshold (study 7)

It has been indicated that the breakpoint between $\dot{V}O_2$ and $\dot{V}CO_2$ is clearer during the ramp exercise test compared to the step-wise exercise test (Jones et al., 2009). As such, data from the ramp exercise test were used to determine the GET for all participants. Two techniques were used to detect the GET: i) V slope method which detects the onset of excess CO_2 output in response to lactate accumulation (Beaver et al., 1986). In this method the $\dot{V}CO_2$ (Y axis) is regressed against the $\dot{V}O_2$ (X axis) and the first disproportionate increase in $\dot{V}CO_2$ relative to the $\dot{V}O_2$ is defined as the GET (Figure 3.6). ii) Ventilatory equivalent for oxygen uptake " $\dot{V}_E/\dot{V}O_2$ " and the ventilatory equivalent for carbon dioxide " $\dot{V}_E/\dot{V}CO_2$ " method (Caiozzo et al., 1982; Davis, 1985). In

this method both the $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$ are regressed against time and the first point at which $\dot{V}_E/\dot{V}O_2$ starts to increase whilst $\dot{V}_E/\dot{V}CO_2$ decreases or fails to show a concomitant increase is defined as the GET (Figure 3.7).

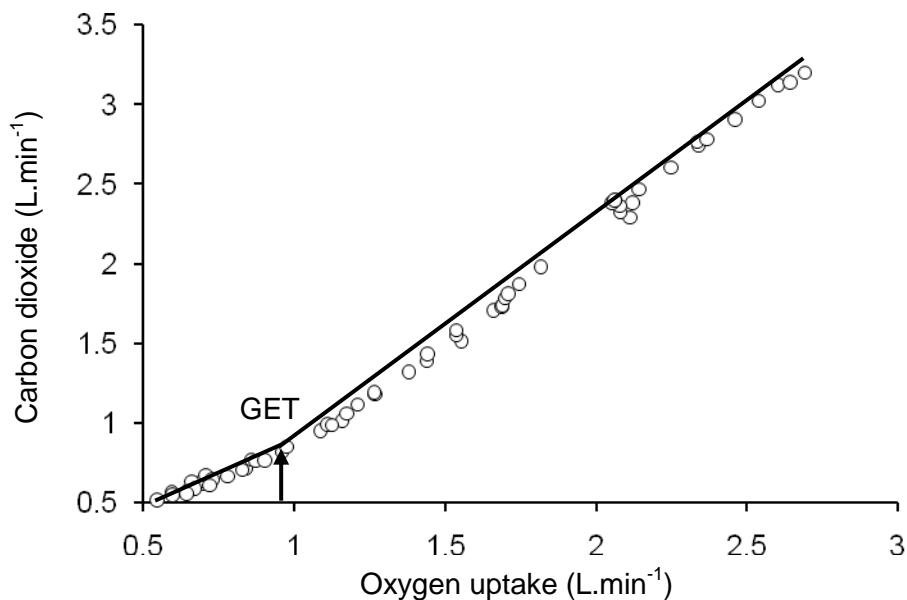


Figure 3.6: $\dot{V}O_2$ regressed against $\dot{V}CO_2$ using the V slope method to determine the GET for an able-bodied participant during an arm cranking ramp exercise test

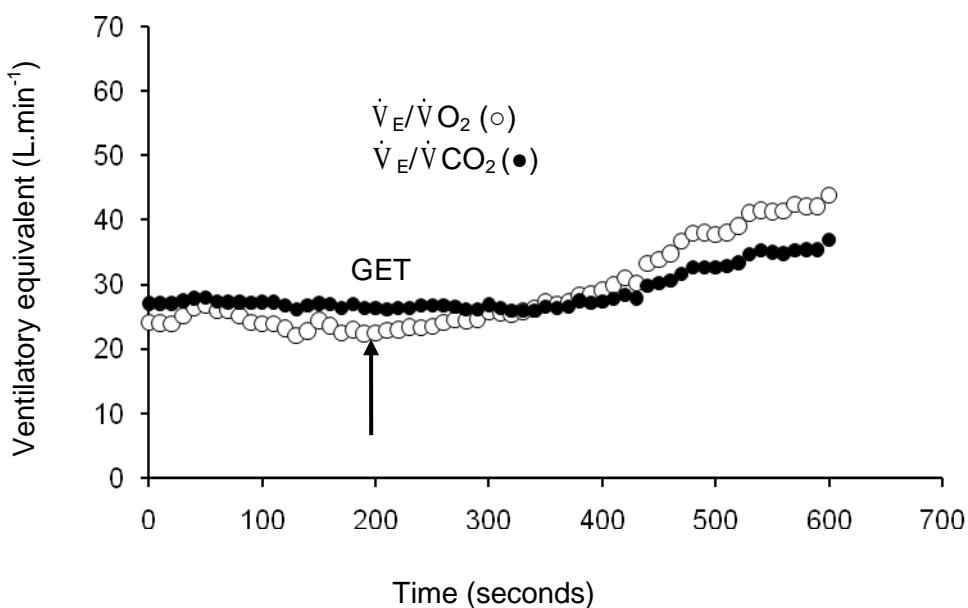


Figure 3.7: $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$ regressed against time to confirm the GET for the same participant

3.9 Constant-load exercise tests (study 6)

Data from the ramp exercise tests were used to determine two different constant-load exercise intensities. After the gas exchange threshold (GET) and the POpeak had been determined; 50% and 70% of the difference between the GET and the POpeak were calculated and then added to the power output at the GET (i.e., 50% Δ and 70% Δ). Participants were requested to exercise at these two constant-load exercise intensities until volitional exhaustion. They were also asked to estimate their RPEo and RPEp at random times in order to avoid giving them information about the duration had elapsed. All information pertaining to physiological (i.e., HR, $\dot{V}O_2$, \dot{V}_E and RER), physical (PO and time) variables were kept out of the participants' sight during these exercise tests.

Chapter four

Study 1

The relationship between perceived exertion and physical and physiological markers of exercise intensity during arm cranking and leg cycling in able-bodied and paraplegic individuals

Data from this chapter have contributed to:

Publication:

Harran Al-Rahamneh, James Faulkner, Christopher Byrne and Roger Eston (2010). Relationship between perceived exertion and physiological markers during arm exercise with able-bodied participants and participants with poliomyelitis. *Archives of Physical Medicine and Rehabilitation*, **91**, 273-277.

Poster presentation:

Harran Al-Rahamneh, James Faulkner, Christopher Byrne and Roger Eston. The relationship between perceived exertion and physiological markers of exercise intensity during arm cranking and leg cycling in able-bodied and individuals with poliomyelitis. BASES Annual Conference 2009, Leeds, UK.

4.1 Introduction

Perception of metabolic and musculoskeletal mediators of exertion plays an important role in the regulation of exercise intensity and compliance to exercise participation (Noble and Robertson, 1996; Borg, 1998; Eston et al., 2009). The Borg 6-20 Ratings of Perceived Exertion (RPE) scale (Borg, 1970; 1998) is widely used to assess sensations of exertion in relation to physiological (heart rate (HR), oxygen uptake ($\dot{V}O_2$), minute ventilation (\dot{V}_E)) and physical (power output (PO), speed) markers that rise commensurately with increments in exercise intensity.

The relationship between the RPE and these markers of exercise intensity are typically derived during either a *passive estimation* or *active production* exercise procedure, and has been consistently shown to be a reliable and valid tool to evaluate whole body exertion during exercise (Skinner et al., 1973a; Skinner et al., 1973b; Borg, 1982; Eston et al., 1987; Chen et al., 2002; Eston et al., 2005, 2006). Correlations greater than $r = 0.85$ have often been shown between the Borg 6-20 RPE scale and heart rate (Borg, 1970; Marriott and Lamb, 1996) and $\dot{V}O_2$ (Eston et al., 2005; 2006; Faulkner and Eston, 2007). Research has primarily focused on applying the RPE with able-bodied men and women of high- and low-fitness during cycle ergometry (Eston et al., 2005, 2006; Faulkner et al., 2007; Eston et al., 2008) and treadmill exercise (Eston et al., 1987; Ceci and Hassmén, 1991; Dunbar et al., 1992; Green et al., 2003). Few studies have directly compared the perceptual response between arm and leg exercise (Pandolf et al., 1984; Borg et al., 1987; Kang et al., 1998; Marais et al., 2001), particularly with regard to the participants' group (i.e., able-bodied and paraplegic).

Research has repeatedly shown that arm exercise produces lower peak physiological values for $\dot{V}O_2$, heart rate and \dot{V}_E and lower peak power output (POpeak) than leg exercise (Åstrand et al., 1965; Bar-Or and Zwirn 1975; Vokac et al., 1975; Kitamura et al., 1981; Franklin et al., 1983; Hagan et al., 1983; Vander et al., 1984; Kang et al., 1997). This has been attributed to the smaller muscle mass activated during upper body exercise compared to the lower body (McArdle et al., 2007).

However, it has also been shown that upper body exercise elicits greater cardiorespiratory, metabolic and perceptual responses than lower body exercise at the same absolute exercise intensity (Åstrand et al., 1965; Vokac et al., 1975; Franklin et al., 1983; Hagan et al., 1983; Vander et al., 1984; Eston and Brodie, 1986; Borg et al., 1987; Kang et al., 1998). This response may be explained by the relationship between the subjective feeling of strain during exercise and the metabolic rate per unit of contracting muscle mass (Åstrand et al., 2003). Research has also shown that at the same absolute intensity during arm exercise, women may achieve a significantly higher RPE, heart rate and \dot{V}_E than men (O'Conner et al., 1996).

Marais et al. (2001) showed that RPE during an upper body incremental exercise test (estimation procedure) was significantly higher at 70, 80, 90, and 100 % of POpeak than lower body exercise (Table 4.1). They postulated that the higher RPE at the higher exercise intensities could be associated with the effect of fatigue during upper body exercise. However, at four constant-load exercise intensities, 4 minutes each, at 20%, 40%, 60% and 80% of POpeak there were no significant difference in the RPE between upper and lower body exercise (Marais et al., 2001; Table 4.2). The RPE has been shown to increase linearly with power output, irrespective of arm or leg exercise (Borg, 1970; Borg et al., 1987; Marais et al., 2001).

Table 4.1: Rating of perceived exertion measured during an incremental exercise test for upper body and lower body. Values are (mean \pm standard deviations (SD)). Note: modified from Marais et al. (2001). *Perceptual and Motor Skills*, 92, 253-262.

Exercise mode	50%	60%	70%	80%	90%	100%
	POpeak	POpeak	POpeak	POpeak	POpeak	POpeak
Upper body	11.1 \pm 1.2	12.7 \pm 1.2	14.2 \pm 1.1*	15.7 \pm 0.9*	17.2 \pm 0.9*	18.8 \pm 0.9*
Lower body	10.8 \pm 1.3	12.2 \pm 0.8	13.5 \pm 1.0	14.7 \pm 1.2	15.9 \pm 1.5	17.2 \pm 1.8

* Significant difference in RPE between upper body and lower body exercise $P < 0.05$

Table 4.2: Rating of perceived exertion measured during a constant-load exercise test at different proportions of POpeak for upper body and lower body. Values are (mean \pm SD). Note: modified from Marais et al. (2001). *Perceptual and Motor Skills*, 92, 253-262.

Exercise mode	20% POpeak	40% POpeak	60% POpeak	80% POpeak
Upper body	9.2 \pm 0.6	10.2 \pm 1.0	11.4 \pm 1.6	13.1 \pm 1.6
Lower body	9.0 \pm 0.0	9.5 \pm 0.9	11.1 \pm 1.1	13.0 \pm 1.5

Research has demonstrated that the RPE is a physiologically valid measure to regulate exercise intensity during arm exercise at both 50% and 70% $\dot{V}O_2$ peak but only at 50% $\dot{V}O_2$ peak during leg exercise (Kang et al., 1998). For both exercise intensities and exercise modes similar $\dot{V}O_2$, heart rate and power output values were reported between estimation and production trials.

A strong relationship between the RPE and physiological markers of exercise intensity have been widely reported for able-bodied participants irrespective of the exercise mode or exercise protocol (Smutok et al., 1980; Eston and Brodie, 1986; Eston et al., 2005, 2006, 2008), age (Gillach et al., 1989), or fitness status of participants (Faulkner and Eston, 2007; Faulkner et al., 2007; Eston et al., 2008), during *passive estimation* and *active production* tasks. Furthermore, research has shown that men and women do not differ in their perception of exertion when comparisons are made at relativized physiological measures of aerobic, metabolic or cardiovascular function (Sydney and Shephard, 1977; Noble et al., 1981; Eston et al., 1987; Robertson et al., 2000; Green et al., 2003).

In comparison, research assessing the perceptual response to exercise in individuals with spinal cord injury (SCI) or disease (SCD) is limited. Whether the RPE may therefore be used to gauge and prescribe appropriate exercise intensities, similar to able-bodied individuals, is unclear. It is widely reported that individuals with SCI have a sedentary lifestyle, which may lead to general physical deconditioning (Zwiren and Bar-Or, 1975; Dicarlo et al., 1983; Davis, 1993; Figoni, 1993). For individuals with SCD and SCI, arm-based exercise may be an appropriate method for exercise participation

Chapter 4: Perceived Exertion and Physical and Physiological Markers of Exercise Intensity as it has been shown to be an effective mode to improve aerobic physical work capacity (Dicarlo, 1982; Dicarlo et al., 1983; Jones et al., 1989; Davis et al., 1990; Kriz et al., 1992; Hicks et al., 2003; Valent et al., 2008).

Individuals with spinal cord injury or spinal cord disease have unique exercise responses. Research has shown that such individuals exhibit different hemodynamic and metabolic responses to exercise compared to their able-bodied counterparts (Davis, 1993; McLean et al., 1995). It has been shown that individuals with spinal cord injury may have abnormal heart rate response due to a loss of sympathetic innervation, which may result in disturbed blood redistribution (Figoni, 1993; Janssen and Hopman, 2005). Furthermore, research has demonstrated that individuals with spinal cord injury experience additional problems that arise from circulatory hypokinesis, such as a lower cardiac output for a given $\dot{V}O_2$, due to blood pooling in the lower limbs (Hjeltnes, 1977; Mathias and Frankel, 1988; Davis et al., 1990). Consequently, the prescription, regulation and monitoring of exercise intensity based upon heart rate, widely used with able-bodied participants, may not be an appropriate method for some individuals with high spinal cord injury due to the attenuated heart rate and cardiovascular response that may develop from the impairment of the autonomic nervous system (Lockette and Keyes, 1994; McLean et al., 1995).

Research that has assessed the perceptual response to exercise in individuals with spinal cord injury is equivocal. Some research has reported perceived exertion to be a useful measure of exercise intensity in a rehabilitation setting for individuals with spinal cord injury or spinal cord disease (Grange et al., 2002; Hicks et al., 2003; Müller et al., 2004; Goosey-Tolfrey et al., 2010). For individuals with paraplegia, Grange et al. (2002) reported RPE to be a useful measure of exercise intensity during supervised wheelchair propulsion. With a similar population and exercise mode, the RPE can be used to accurately reproduce exercise intensities (Müller et al., 2004). It has been suggested that the RPE may be an appropriate measure to prescribe exercise intensity (McLean et al., 1995; Hicks et al., 2003). More recently, Goosey-Tolfrey, (2010)

Chapter 4: Perceived Exertion and Physical and Physiological Markers of Exercise Intensity
observed no significant differences in heart rate, % HRpeak, $\dot{V}O_2$, % $\dot{V}O_2$ peak and blood lactate level between prescribed exercise intensities based on 50% and 70% $\dot{V}O_2$ peak and regulated ones using RPE. However, research has shown that during a peak graded arm ergometry test, perceptual responses (RPE) from paraplegic and tetraplegic individuals did not correlate significantly with heart rate, $\dot{V}O_2$ or \dot{V}_E (Lewis et al., 2007). The authors suggested that the RPE may not be a valid psychophysiological index of perceived exertion in persons with spinal cord injury. This is in accordance with previous research which has indicated that RPE is not a suitable indicator of exercise intensity in persons with spinal cord injury using functional neuromuscular stimulation during shuttle walking (Jacobs et al., 1997).

The purpose of this study was to assess the strength of the relationship between the RPE and physiological (i.e., $\dot{V}O_2$, HR and \dot{V}_E) and physical (i.e., PO) indicators of exercise intensity and whether the strength of these relationships were moderated by either the exercise mode (i.e., arm cranking and leg cycling), participants' group (i.e., able-bodied and paraplegic) and gender (i.e., men and women). We hypothesized that strong relationships would be evident between the RPE and each of the physiological and physical markers of exercise intensity, and that the relationships would not be moderated by the exercise mode and participants' group or gender.

4.2 Methods

Participants

In accordance with an alpha less than 0.05 (2-tailed) and 80% power, it was determined that a meaningful effect size would be obtained from a sample of greater than 30 participants (Cohen, 1992). Therefore, nine able-bodied men and eight men with paraplegia, and seven able-bodied women and seven women with paraplegia, volunteered to take part in the study. Their demographic information can be seen from Table 4.3. Able-bodied (Able) participants were physical education students who were healthy and free from illnesses and pre-existing injury. Paraplegic (Para) participants

Chapter 4: Perceived Exertion and Physical and Physiological Markers of Exercise Intensity had a flaccid paralysis of the lower limbs as a result of poliomyelitis infection. Paraplegic participants had no complications with their upper-body and cardiorespiratory system. All participants had no prior experience of perceptual scaling with the Borg 6-20 RPE scale. Please see section (*3.1 Measurement of height and body mass (for all the studies)*) for more details about how height and body mass were measured.

This study was conducted in agreement with institutional ethics approval from the Faculty of Physical Education at the University of Jordan. All exercise tests were performed in the physiology laboratory at the Faculty of Physical Education at the University of Jordan.

Table 4.3: Demographic information for all participants. Values are (mean \pm SD).

	Able-bodied Men (n = 9)	Paraplegic Men (n = 8)	Able-bodied Women (n = 7)	Paraplegic Women (n = 7)
Age (y)	20.3 \pm 0.5	35.0 \pm 4.0*	20.8 \pm 0.8	33.4 \pm 5.0°
Height (cm)	176.2 \pm 6.0	168.0 \pm 10.1*	162.0 \pm 6.4	147.4 \pm 5.0°
Body mass (kg)	70.4 \pm 17.1	71.0 \pm 16.2	56.4 \pm 7.6	55.1 \pm 12.0

* Significant difference between able-bodied and paraplegic men $P < 0.05$

° Significant difference between able-bodied and paraplegic women $P < 0.05$

Procedures

Each participant (i.e., able-bodied and paraplegic) performed an arm cranking ramp exercise test designed to establish peak functional capacity for the upper limbs (Figure 4.1). All able-bodied participants also completed a recumbent leg cycling ramp exercise test designed to establish peak functional capacity for the lower limbs. Able-bodied participants had approximately 48 hours recovery period between exercise tests. All participants were recommended to avoid moderate to vigorous exercise in the days between and prior to the exercise tests. Please see sections (*3.3 gas analysis and 3.4 arm ergometry*) for more details about gas analyzer and arm ergometry used, respectively.



Figure 4.1: An individual performing an arm cranking exercise. Note: this photo was used with a written permission from the participant

Measures

Borg 6-20 RPE scale

Participants reported their overall feeling of exertion in the remaining 20 s of each minute of the exercise tests and at the completion of the exercise test. Please see section (3.2 *Borg 6-20 RPE Scale*) for more details.

Leg cycling ramp exercise test

The test commenced with participants performing 4 minutes warm-up at 0 W. The increments in power output were $24 \text{ W} \cdot \text{min}^{-1}$ and $12 \text{ W} \cdot \text{min}^{-1}$ for men and women, respectively. Please see section (3.5 *Ramp exercise test, Leg cycling ramp exercise test (study 1)*) for more details and for criteria of terminating the exercise test. During the last 20 seconds (s) of every minute of the ramp exercise tests, and at the completion of the exercise test, participant's estimated their overall RPE. A blood sample was collected from a fingertip into a capillary tube after the termination of the exercise immediately. Blood samples were then analyzed to determine blood lactate concentration (YSI 1500, Yellow Springs Instruments, Yellow Springs, OH). Following completion of the test, participants were encouraged to pedal against a light resistance (0 W) and perform some stretching exercises to aid recovery.

Arm cranking ramp exercise test

Following 4 minutes warm up at 0 W, the increments in power output were 15 W. min^{-1} and 6 W. min^{-1} for able-bodied men and women, respectively. A 9 W. min^{-1} and 6 W. min^{-1} increments in power output were more appropriate for the paraplegic men and women, respectively. Please see section (*3.5 Ramp exercise test, Arm cranking ramp exercise test (study 1 & 2)*) for more details and for criteria of terminating the exercise test. A blood sample was collected from a fingertip into a capillary tube after the termination of the exercise immediately. Blood samples were then analyzed to determine blood lactate concentration (YSI 1500, Yellow Springs Instruments, Yellow Springs, OH). Following completion of the test, participants were encouraged to pedal against a light resistance (0 W) and perform some stretching exercises to aid recovery.

Data analysis

Descriptive statistics

A series of independent-sample t-tests were performed to investigate whether there was a significant difference between men and women in the peak values for $\dot{\text{V}}\text{O}_2$, heart rate, $\dot{\text{V}}_E$, RER, lactate, RPE, and PO observed at the termination of the leg cycling exercise test. A similar analysis was performed to assess whether there was a significant difference between men and women in the same variables at the termination of the arm cranking exercise test for able-bodied and paraplegic participants. Further analysis was used to assess whether there was a significant difference between able-bodied and paraplegic individuals in these variables at the termination of the arm cranking exercise tests.

A series of two factor ANOVAs (Exercise mode; arm crank and leg cycling x Gender; men and women), were used to compare the physiological ($\dot{\text{V}}\text{O}_2\text{peak}$, HRpeak, RER, $\dot{\text{V}}_E\text{peak}$, Lactate), perceptual (RPE), physical (POpeak) values observed at the termination of the arm cranking and leg cycling exercise tests for able-bodied participants.

Relationships between the RPE and physical and physiological markers of exercise intensity during the arm cranking and leg cycling

The RPE values reported during the last 20 s of each minute and at the termination of the exercise tests, for both arm cranking and leg cycling, were regressed against the corresponding mean $\dot{V}O_2$, HR and $\dot{V}E$ in a linear regression analysis for each participant (Figure 4.2). The mean RPE, HR and $\dot{V}O_2$ values observed during the last 20 s of each minute and at the completion of the exercise test, for both arm cranking and leg cycling, were regressed against the corresponding PO in a linear regression analysis for each participant.

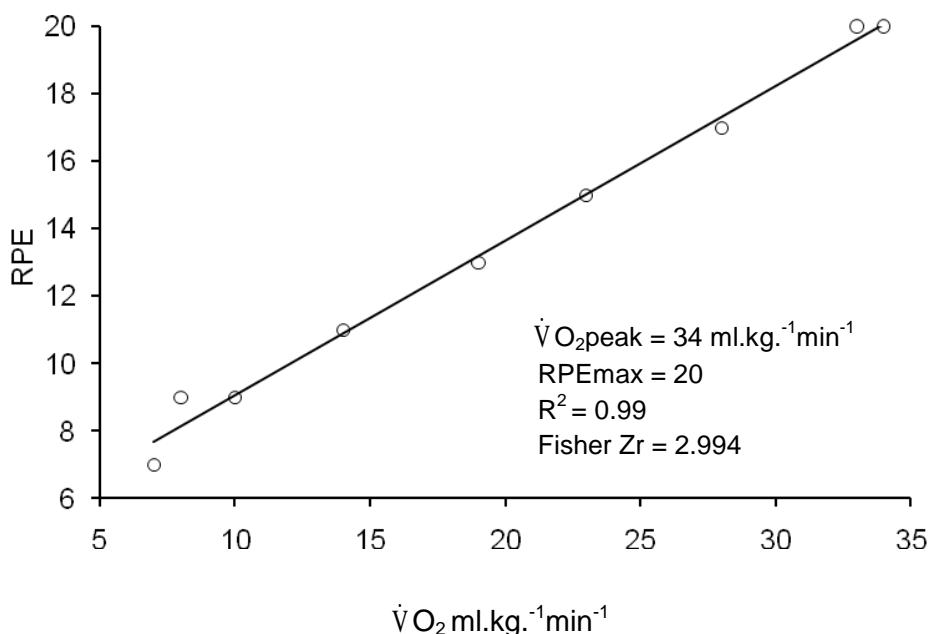


Figure 4.2: Individual $\dot{V}O_2$ and RPE values reported at the completion of each minute of an able-bodied male participant during an arm crank exercise test

Individual R squared (R^2) values were obtained for each participant to identify the relationship between the RPE and physiological markers of exercise intensity (RPE: $\dot{V}O_2$, RPE: HR, RPE: $\dot{V}E$, PO: RPE, PO: HR and PO: $\dot{V}O_2$) throughout the duration of the arm cranking and leg cycling exercise tests. All R^2 values calculated via the linear regression analyses were converted to Fisher Zr values to approximate for the normality of the sampling distribution (Thomas et al., 2005). This was deemed appropriate as research has shown that the sampling distribution of correlation coefficients may not be normally distributed (Thomas et al., 2005).

A series of independent-sample t-tests were used to assess the influence of gender on the strength of the relationships between the RPE: $\dot{V}O_2$, RPE: HR, RPE: \dot{V}_E , PO: RPE, PO: $\dot{V}O_2$ and PO: HR during the leg cycling exercise test. A series of two factor ANOVAs (Exercise mode; arm cranking and leg cycling x Gender; male and female) were also used to assess each of the aforementioned relationships for all able-bodied participants during the two exercise modes and whether gender moderated any of these relationships.

Three factor ANOVA (Zr values of the bivariate combinations; RPE: $\dot{V}O_2$, RPE: HR, RPE: \dot{V}_E ; Gender; men and women x Group; able-bodied and paraplegic) was used to assess whether there were significant differences in the strength of these relationships during the arm cranking exercise test and whether gender and/or participants' group moderated the strength of these relationships. Identical statistical procedures were used to assess the relationships observed between PO: RPE, PO: $\dot{V}O_2$ and PO: HR during the arm cranking exercise test. If data violated assumptions of sphericity using the Mauchly's test of sphericity, the Greenhouse-Geisser correction factor was applied to correct the degrees of freedom (Winter et al., 2001; Field, 2009). Alpha was set at 0.05 and adjusted accordingly. Post hoc analysis using paired sample and independent-sample t-tests were performed where appropriate, following a Bonferroni adjustment, to identify any significant differences in the strength of the relationships.

Comparison of the b coefficient slopes of RPE against PO

For each individual, the RPE values were regressed against PO and the percentage of peak PO in both the arm cranking and leg cycling exercise tests using RPE as the dependent variable (y axis) and PO (x axis) as the independent variable. A series of two factor ANOVAs (Exercise mode; arm cranking and leg cycling x Gender; male and female) were used to identify whether the *b* coefficients for able-bodied participants were different between the arm cranking and leg cycling exercise tests when the RPE was expressed against absolute PO and as a percentage of POpeak.

Independent-sample t-tests were also used to assess whether the rate of change in the RPE (b coefficients) during the arm cranking exercise test was moderated by the participants' group (i.e., able-bodied and paraplegic) when expressed against absolute PO and as a percentage of POpeak. In addition, independent-sample t-tests were used to assess the influence of gender on the rate of change in the RPE (i.e., absolute and relative) for able-bodied and paraplegic participants during the arm cranking exercise test. Alpha was set at 0.05 and adjusted accordingly. Data were analyzed using Statistical Package for Social Sciences (SPSS) for windows version 16.

4.3 Results

Descriptive statistics

The descriptive statistics for physiological, physical and perceptual variables reported at the termination of both leg cycling and arm cranking exercise tests can be observed in table 4.4 and 4.5, respectively.

Table 4.4: Descriptive statistics for physiological, perceptual and physical variables observed at the termination of the leg cycling exercise test for able-bodied men and women. Values are (mean \pm SD).

Gender	$\dot{V}O_2$ peak (L·min $^{-1}$)	$\dot{V}O_2$ peak (ml·kg $^{-1}$ ·min $^{-1}$)	HRpeak (b·min $^{-1}$)	\dot{V}_E peak (L·min $^{-1}$)	Blood lactate (m·mol $^{-1}$)	RPE (overall)	POpeak (W)	Time (minutes)
Able-bodied men	3.00 \pm 0.39*	44 \pm 8*	169 \pm 11	99 \pm 23*	8.6 \pm 2.6	19.9 \pm 0.3	241 \pm 30*	9.84 \pm 1.28
Able-bodied women	1.55 \pm 0.43	28 \pm 8	169 \pm 15	54 \pm 5	8.9 \pm 3.6	19.9 \pm 0.4	121 \pm 12	9.96 \pm 1.02

* Significant difference between men and women at $P < 0.05$

Table 4.5: Descriptive statistics for physiological, perceptual and physical variables observed at the termination of the arm cranking exercise test for able-bodied and paraplegic men and women. Values are (mean \pm SD).

Group/ Gender	$\dot{V}O_2$ peak (L·min $^{-1}$)	$\dot{V}O_2$ peak (ml·kg $^{-1}$ ·min $^{-1}$)	HRpeak (b·min $^{-1}$)	\dot{V}_E peak (L·min $^{-1}$)	Blood lactate (m·mol $^{-1}$)	RPE (overall)	POpeak (W)	Time (minutes)
Able-bodied men	1.96 \pm 0.32	28 \pm 5°	163 \pm 19	73 \pm 17°	8.0 \pm 2.0	19.6 \pm 0.7	120 \pm 13*°	7.87 \pm 0.78
Able-bodied women	1.07 \pm 0.19	19 \pm 2	161 \pm 17	41 \pm 5	9.0 \pm 2.3	19.6 \pm 0.8	54 \pm 8	8.86 \pm 1.42
Paraplegic men	1.65 \pm 0.40	24 \pm 4 ⁺	165 \pm 14	65 \pm 18 ⁺	8.4 \pm 2.0	19.4 \pm 1.1	96 \pm 27 ⁺	10.50 \pm 2.47
Paraplegic women	1.01 \pm 0.14	19 \pm 4	156 \pm 20	43 \pm 8	9.0 \pm 3.1	18.7 \pm 1.1	53 \pm 6	8.77 \pm 0.93

* Significant difference between able-bodied and paraplegic men $P < 0.05$

° Significant difference between able-bodied men and able-bodied women $P < 0.05$

⁺ Significant difference between paraplegic men and paraplegic women $P < 0.05$

Leg cycling exercise test

Independent-sample t-tests revealed that men achieved significantly higher values for $\dot{V}O_2$ peak ($t_{(14)} = 4.1, P < 0.01$), POpeak ($t_{(10.7)} = 10.9, P < 0.001$) and \dot{V}_E peak ($t_{(9.1)} = 5.6, P < 0.001$) compared to women. There were no significant differences in the peak values for RPE ($t_{(14)} = 0.2, P > 0.05$), lactate accumulation ($t_{(14)} = 0.2, P > 0.05$) and heart rate ($t_{(14)} = 0.0, P > 0.05$) between men and women during leg cycling. In addition, there was no significant difference in time to exhaustion between men and women ($t_{(14)} = 0.2, P > 0.05$). These descriptive values can be seen from Table 4.4.

Arm cranking vs. leg cycling

As expected, two factor ANOVAs revealed significantly higher peak values for $\dot{V}O_2$ ($F_{(1, 14)} = 51.4, P < .001$), PO ($F_{(1, 14)} = 276.4, P < .001$) and \dot{V}_E ($F_{(1, 14)} = 32.5, P < .001$) during leg cycling compared to arm cranking exercise. There was no significant exercise mode x gender interaction on $\dot{V}O_2$ peak ($F_{(1, 14)} = 4.3, P = 0.057$) or \dot{V}_E peak ($F_{(1, 14)} = 4.0, P = 0.065$). However, there was a significant exercise mode x gender interaction on POpeak ($F_{(1, 14)} = 22.3, P < 0.001$). There were no significant differences in peak values of RPE, heart rate or lactate between the two exercise modes (all $P > 0.05$). There was no significant exercise mode x gender interactions on the peak values of heart rate, RPE and lactate accumulation (all $P > 0.05$). Although no significant difference in the peak RER values were observed between the two exercise modes ($F_{(1, 14)} = 3.0, P > 0.05$), there was a significant exercise mode x gender interaction on RER values ($F_{(1, 14)} = 4.8, P = 0.46$). Men reported a similar peak RER during arm cranking and leg cycling exercise tests (1.08 ± 0.07 and 1.06 ± 0.08 , respectively) but a much larger difference was observed for the women (1.06 ± 0.08 and 1.18 ± 0.12 , respectively). Finally, participants exercised for significantly longer duration during leg cycling compared to arm cranking ($F_{(1, 14)} = 22.5, P < 0.001$). There was no significant difference between men and women in time to exhaustion ($F_{(1, 14)} = 1.4, P > 0.05$) and

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no significant exercise mode x gender interaction on time to exhaustion ($F_{(1, 14)} = 1.8, P > 0.05$).

Arm cranking exercise test

Independent-sample t-tests revealed that able-bodied men achieved significantly higher peak values for $\dot{V}O_2$ ($t_{(14)} = 4.7, P < 0.001$), PO ($t_{(14)} = 12.0, P < 0.001$) and \dot{V}_E ($t_{(14)} = 4.6, P < 0.001$) during arm cranking exercise compared to their women counterparts. However, no significant differences were observed between men and women in the peak values for heart rate, RPE and lactate (all $P > 0.05$). In addition, no significant difference was observed between men and women in time to exhaustion ($t_{(8,8)} = 1.7, P > 0.05$).

Independent-sample t-tests revealed that paraplegic men achieved significantly higher peak values for $\dot{V}O_2$ ($t_{(13)} = 2.3, P < 0.05$), PO ($t_{(13)} = 4.1, P < 0.01$) and \dot{V}_E ($t_{(13)} = 3.0, P < 0.05$) during arm cranking exercise compared to their women counterparts. However, no significant differences were observed between men and women in the peak values for heart rate, RPE and lactate (all $P > 0.05$). In addition, no significant difference was observed between men and women in time to exhaustion ($t_{(13)} = 1.5, P > 0.05$).

Independent-sample t-tests revealed that able-bodied men achieved significantly higher peak values for $\dot{V}O_2$ ($t_{(15)} = 2.21, P < 0.05$) and PO ($t_{(15)} = 2.5, P < 0.05$) than their paraplegic counterparts. Time to exhaustion was significantly longer ($t_{(15)} = 2.6, P < 0.05$) for paraplegic persons compared to their able-bodied counterparts. There were no significant differences in the peak values for \dot{V}_E , heart rate, RPE and lactate between the two groups (all $P > 0.05$). However, when controlled for age (covariate) using ANCOVA the differences in $\dot{V}O_2$ peak and POpeak diminished between the two groups ($P > 0.05$). Further independent-sample t-tests revealed no significant differences in all the peak values between able-bodied and paraplegic women (all $P > 0.05$).

Finally, independent-sample t-tests revealed significantly higher peak values for $\dot{V}O_2$ ($t_{(29)} = 4.7, P < 0.001$), \dot{V}_E ($t_{(20.8)} = 5.9, P < 0.001$) and PO ($t_{(19.2)} = 9.3, P < 0.001$) for men compared to women, irrespective of group. There were no significant differences between men and women, irrespective of group, in the peak values for HR, RPE and lactate (all $P > 0.05$). No significant difference in time to exhaustion was observed between men and women, regardless of group, ($t_{(29)} = 0.0, P > 0.05$). All peak physiological, physical and perceptual values observed at the termination of arm cranking exercise tests can be seen from Table 4.5.

Relationships between the RPE and physiological and physical markers of exercise intensity

The relationship between the RPE and physiological markers of exercise intensity and power output and perceptual and physiological markers of exercise intensity are presented in Table 4.6.

Table 4.6: Mean R^2 values for the relationships between $\dot{V}O_2$: RPE, HR: RPE, \dot{V}_E : RPE, PO: RPE, PO: $\dot{V}O_2$ and PO: HR, when reconverting Fisher Zr scores to R^2 values during arm cranking and leg cycling exercise tests for able-bodied and paraplegic participants and for men and women

Group/Mode	RPE: $\dot{V}O_2$	RPE:HR	RPE: \dot{V}_E	PO:RPE	PO: $\dot{V}O_2$	PO:HR
Leg Able men	0.96	0.97*	0.92	0.96	0.98	0.98*
Leg Able women	0.95	0.97*	0.92	0.98	0.97	0.98*
Arm Able men	0.94°	0.90	0.87	0.95	0.98°	0.97
Arm Able women	0.93°	0.95	0.90	0.96	0.96°	0.95
Arm Para men	0.87	0.93	0.90	0.94	0.95	0.98
Arm Para women	0.87	0.93	0.92	0.95	0.95	0.98

* Significant difference between arm cranking and leg cycling $P < 0.05$

° Significant difference between able-bodied and paraplegic $P < 0.05$

Leg cycling exercise test

Linear regression analyses of individual RPE: $\dot{V}O_2$, RPE: HR and RPE: \dot{V}_E , produced average R^2 values of $R^2 = 0.92$ to $R^2 = 0.97$, regardless of gender, when reconverting Fisher Zr scores to R^2 values (Table 3.6). Similar values were reported between PO: RPE, PO: $\dot{V}O_2$ and PO: HR ($R^2 = 0.96$ to $R^2 = 0.98$). A series of independent-sample t-tests revealed no significant differences in the strength of the relationships between men and women for each of the relationships reported in Table 4.6 (all $P > 0.05$).

A series of paired sample t-test revealed a stronger overall relationship between RPE: HR than overall relationship between RPE: \dot{V}_E ($t_{(15)} = 3.6$, $P < 0.01$). Further, paired sample t-tests revealed a stronger overall relationship between PO: HR than both overall relationship between PO: RPE ($t_{(15)} = 3.4$; $P < 0.01$) and PO: $\dot{V}O_2$ ($t_{(15)} = 2.2$, $P < 0.05$). These differences could be considered of negligible importance since all these relationships have R^2 values of 0.92 or above as can be seen from Table 4.6.

Arm cranking vs. leg cycling

A series of two factor ANOVAs demonstrated no significant differences between arm cranking and leg cycling exercise tests for able-bodied participants in the strength of the relationship between the RPE: $\dot{V}O_2$ ($F_{(1, 14)} = 1.0$, $P > 0.05$) and between the RPE: \dot{V}_E ($F_{(1, 14)} = 1.8$, $P > 0.05$). However, as shown in Table 4.6, ANOVA revealed a significantly stronger relationship between the RPE: HR during leg cycling exercise compared to arm cranking ($F_{(1, 14)} = 7.4$, $P < 0.05$). No significant differences were observed between men and women in the strength of these relationships (all $P > 0.05$) and no significant exercise mode x gender interactions were observed on the strength of these relationships (all $P > 0.05$).

There was no significant differences between arm cranking and leg cycling in the strength of the relationships between PO: $\dot{V}O_2$ ($F_{(1, 14)} = 1.5$, $P > 0.05$) and between PO: RPE ($F_{(1, 14)} = 2.1$, $P > 0.05$). However, there was significantly stronger relationship for PO: HR during leg cycling exercise tests compared to arm cranking (F

($_{(1, 14)}$ = 13.2, $P < 0.01$). There was no significant exercise mode x gender interactions on the strength of these relationships (all $P > 0.05$). There were no significant differences between men and women in the strength of the relationships between PO: RPE and between PO: HR (all $P > 0.05$).

Arm cranking exercise test

Linear regression analyses of individual RPE: $\dot{V}O_2$, RPE: HR and RPE: \dot{V}_E , produced average R^2 values of $R^2 = 0.87$ to $R^2 = 0.95$, regardless of participants' gender or group, when reconverting Fisher Zr scores to R^2 values (Table 4.6).

Three factors ANOVA (Zr values of the bivariate combinations; RPE: $\dot{V}O_2$, RPE: HR, RPE: \dot{V}_E x Gender; men and women x Group; able-bodied and paraplegic) revealed that there were no significant differences in the overall relationships between RPE: $\dot{V}O_2$, RPE: HR and RPE: \dot{V}_E , ($F_{(2, 54)} = 2.2$, $P > 0.05$). There were no significant differences between men and women ($F_{(1, 27)} = 0.4$, $P > 0.05$) or between able-bodied and paraplegic individuals in these relationships ($F_{(1, 27)} = 0.3$, $P > 0.05$). There was no significant group x gender interaction on these relationships ($F_{(1, 27)} = 0.4$, $P > 0.05$). There was no significant interaction between these relationships and gender ($F_{(2, 54)} = 0.4$, $P > 0.05$) and no significant interaction between these relationships x gender x group ($F_{(2, 54)} = 0.8$, $P > 0.05$). However, it did reveal that there was a significant interaction between these relationships and group ($F_{(2, 54)} = 4.9$, $P < 0.05$). Post hock independent-sample t-tests analysis, using Bonferroni adjustment ($P = 0.017$), showed that able-bodied participants have stronger relationship between RPE: $\dot{V}O_2$ than their paraplegic counterparts ($t_{(29)} = 2.4$, $P = 0.022$).

A similar analysis was used to assess the strength of the relationship between PO and the RPE, $\dot{V}O_2$ and HR. Linear regression analyses of individual PO: $\dot{V}O_2$, PO: HR and PO: RPE, produced average R^2 values of $R^2 = 0.94$ to $R^2 = 0.98$, regardless of gender or group, when reconverting Fisher Zr scores to R^2 values (Table 4.6).

Three factors ANOVA revealed significant differences in the overall relationship (R^2 values) between the PO: RPE, PO: HR and PO: $\dot{V}O_2$ ($F_{(2, 54)} = 3.7$, $P < 0.05$). Post

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hoc paired samples t-tests, using Bonferroni adjustment ($P = 0.017$), demonstrated a stronger relationship between PO: HR than PO: RPE ($t_{(30)} = 2.4$, $P = 0.022$). There were no significant differences between men and women ($F_{(1, 27)} = 1.1$, $P > 0.05$) or between able-bodied and paraplegic individuals in these relationships ($F_{(1, 27)} = 0.3$, $P > 0.05$). There was no significant group x gender interaction on these relationships ($F_{(1, 27)} = 0.7$, $P > 0.05$). There was no significant interaction between these relationships and gender ($F_{(2, 54)} = 1.6$, $P > 0.05$) and no significant interaction between these relationships x gender x group ($F_{(2, 54)} = 0.8$, $P > 0.05$). However, it did reveal that there was a significant interaction between these relationships and group ($F_{(2, 54)} = 3.6$, $P < 0.05$). Post hoc independent sample t-test, using Bonferroni adjustment ($P = 0.017$), showed that the average relationship between PO: $\dot{V}O_2$ was significantly higher for able-bodied participants than their paraplegic counterparts ($t_{(29)} = 2.6$, $P < 0.017$).

Comparison of the b coefficient slopes of RPE against PO

Leg cycling exercise test

The RPE increased at significantly higher rate of change during leg cycling for able-bodied women compared to men ($t_{(7,6)} = 6.5$, $P < 0.05$; $b = 0.12$ and $b = 0.06$, respectively) when the RPE was regressed against absolute power output. However, these differences in the rate of change of the RPE between men and women disappeared when the RPE regressed against percentages of power output ($t_{(14)} = 0.1$, $P > 0.05$; $b = 0.15$ and $b = 0.15$, respectively).

Arm cranking vs. leg cycling

A comparison of the within-subject slopes between arm and leg exercise for able-bodied participants indicated that the rate of increase in the RPE when expressed against absolute PO was significantly greater ($F_{(1, 14)} = 55.2$, $P < 0.001$) during arm cranking ($b = 0.18 \pm 0.10$) than leg cycling exercise ($b = 0.09 \pm 0.04$). Women had significantly faster rate of change in the RPE compared to men ($F_{(1, 14)} = 32.8$, $P < 0.001$; $b = 0.20 \pm 0.02$ vs. $b = 0.09 \pm 0.01$, respectively). There was a significant interaction between the rate of change in the RPE and gender ($F_{(1, 14)} = 15.0$, $P <$

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0.01), with a significantly faster rate of change in the RPE in women during arm cranking compared to leg cycling.

When the RPE was expressed as a percentage of POpeak, the rate of change in the RPE for arm cranking exercise was significantly lower than for leg cycling ($F_{(1,14)} = 6.0$, $P < 0.05$; $b = 0.14 \pm 0.03$ and $b = 0.15 \pm 0.03$, respectively). The differences between men and women disappeared when the RPE regressed against %PO during both modes of exercise ($F_{(1,14)} = 0.1$, $P > 0.05$) and no significant interaction between the rate of change in the RPE and gender ($F_{(1,14)} = 0.9$, $P > 0.05$).

Arm cranking exercise test

Independent-sample t-tests revealed that able-bodied women had significantly faster rate of change in the RPE when regressed against PO compared to their men counterparts ($t_{(6,4)} = 4.5$, $P < 0.05$; $b = 0.27 \pm 0.09$ and $b = 0.11 \pm 0.02$, respectively (Figure 4.3)). Paraplegic women had faster rate of change in the RPE when regressed against PO compared to their paraplegic men ($t_{(13)} = 2.1$, $P = 0.053$; $b = 0.22 \pm 0.08$ and $b = 0.14 \pm 0.05$, respectively). Paraplegic men had faster rate of change in the RPE compared to their able-bodied men ($t_{(15)} = 2.1$, $P = 0.055$). However, these differences between able-bodied men and women (Figure 4.4), paraplegic men and women and between able-bodied and paraplegic men disappeared when the RPE regressed against proportion of power output (%PO). Similar rate of change in the RPE was observed between able-bodied and paraplegic women when the RPE regressed against PO ($t_{(12)} = 1.2$, $P > 0.05$) and %PO ($t_{(12)} = 1.6$, $P > 0.05$).

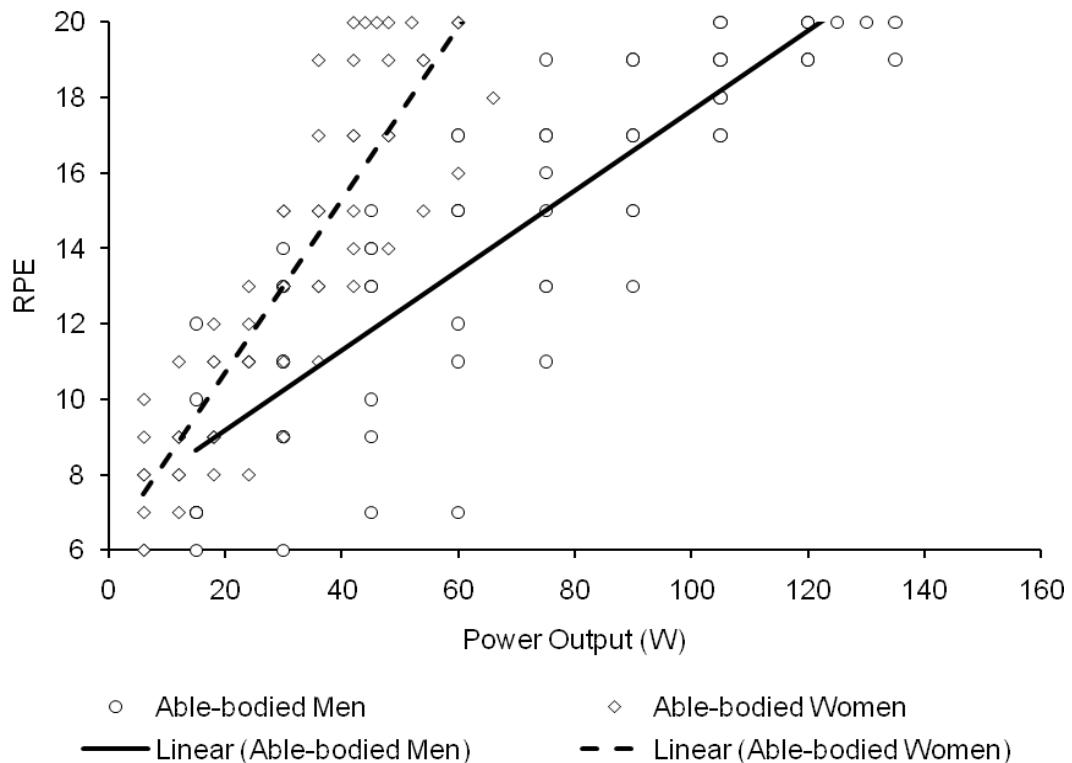


Figure 4.3: Scatterplot illustrating the RPE and PO relationship during arm cranking exercise for able-bodied men and women participants

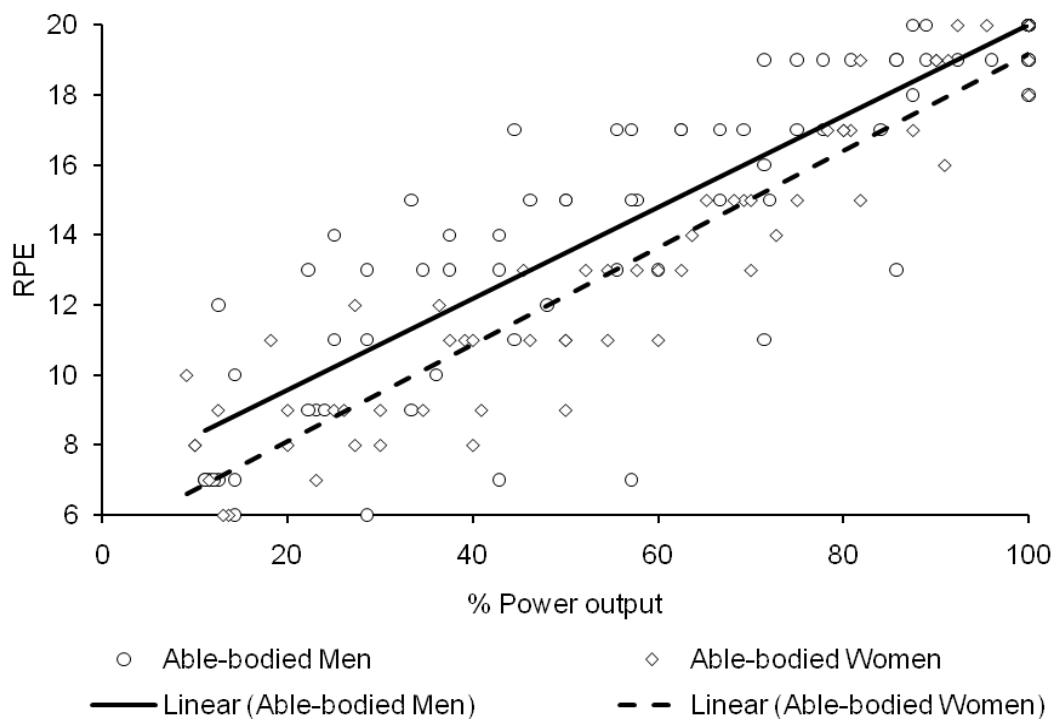


Figure 4.4: Scatterplot illustrating the RPE and %PO relationship during arm cranking exercise for able-bodied men and women participants

4.4 Discussion

This study assessed the physiological and perceptual responses of able-bodied and individuals with paraplegia during arm cranking and leg cycling ramp exercise tests to volitional exhaustion. To our knowledge this is the first study which has assessed the perceptual response of Arabic individuals during incremental arm and leg exercise tests. This study provides further evidence that the RPE is a valid and reliable tool to evaluate overall exertion during arm cranking and leg cycling exercise tests for able-bodied and paraplegic individuals, irrespective of gender.

Descriptive statistics at volitional exhaustion

As expected this study supports previous research which has shown that arm exercise produces lower peak values for $\dot{V}O_2$, heart rate, \dot{V}_E and power output in comparison to leg exercise (Schwade et al., 1977; Franklin et al., 1983; Hagan et al., 1983; Vander et al., 1984; Pendergast, 1989; Aminoff et al., 1996; Muraki et al., 2004). This finding was observed irrespective of gender. It may be suggested that these differences are attributed to the smaller muscle mass activated during arm cranking exercise compared to leg cycling (McArdle et al., 2007).

The present study demonstrated no differences in maximal RPE or blood lactate values observed at the termination of the ramp exercise test for both arm and leg exercise. The findings of similar maximal RPE between the two modes of exercise concurs with research by Franklin et al. (1983), Vander et al. (1984) and Aminoff et al. (1996), but not with the study of Marais et al. (2001). They observed a lower maximal RPE during lower body than upper body exercise (17.2 ± 1.8 and 18.8 ± 0.9 , respectively) at the termination of a maximal incremental exercise test. The difference in findings may be due to the protocol design. In the latter study the RPE was assessed after completing 2 minutes of exercise at 50, 60, 70, 80, 90 and 100 % PO_{peak}. As the present study used a ramp protocol to increase the exercise intensity, the smaller but more regular manipulations in exercise intensity may have elicited a more accurate perception of exertion at the completion of both arm cranking and leg cycling exercise

Chapter 4: Perceived Exertion and Physical and Physiological Markers of Exercise Intensity tests. Nevertheless, the lower RPE elicited during lower body exercise in the study by Marais et al. (2001) is surprising, considering that recent research that has utilised a step increase in exercise intensity during cycle ergometry has been widely shown to produce a maximal RPE of 19 or 20 at volitional exhaustion (Eston et al., 2005, 2006, 2008; Faulkner and Eston 2007; Faulkner et al., 2007, 2009).

The similar blood lactate values at the termination of the two modes of exercise are not in agreement with previous research (Bevegard et al., 1966; Stenberg et al., 1967; Hagan et al., 1983). These studies have demonstrated higher maximal blood lactate concentrations for arm cranking compared to leg cycling exercise. In the present study similar maximal blood lactate values were observed between the two exercise modes ($\sim 8.0\text{-}9.0 \text{ m}\cdot\text{mol}^{-1}$). This might be due to the different increments in power output utilised during the ramp exercise tests for both exercise modes. Subsequently, both arm and leg were exercising at a relatively adequate power output until exhaustion.

Able-bodied men achieved higher peak values for PO, $\dot{V}\text{O}_2$ and $\dot{V}\text{E}$ at the termination of leg cycling than their women counterparts. In addition, men achieved higher peak values for PO, $\dot{V}\text{O}_2$ and $\dot{V}\text{E}$ at the termination of arm cranking exercise test than women, irrespective of group. Generally speaking, this gender differences may be attributed to that men have more muscle mass, less percentage of body fat, more blood volume, more red blood cells, higher maximal cardiac output, higher maximal stroke volume, larger thoracic cavity and they are more physically active than women (Janssen et al., 2000; Wilmore, 2005; McArdle et al., 2007; Eston and Romer, 2009).

This study showed that able-bodied men have a significantly higher POpeak and $\dot{V}\text{O}_2\text{peak}$ than their paraplegic counterparts. This is in agreement with Hooker et al. (1993) who observed that able-bodied achieved higher peak values for PO, $\dot{V}\text{O}_2$ and $\dot{V}\text{E}$ than their counterparts with SCI. Similarly, Nollet et al. (2004) observed a significantly higher PO, $\dot{V}\text{O}_2$ and $\dot{V}\text{E}$ at the termination of cycle ergometry tests for able-bodied than individuals with poliomyelitis. These differences in POpeak and

$\dot{V}O_2$ peak may be attributed to the fact that able-bodied use their trunk and leg muscles for stabilization and as a fulcrum from which to push (Janssen and Hopman, 2005). Alternatively this might be attributed to age differences between the two groups since paraplegic individuals were significantly older than their able-bodied counterparts; especially when considering that these differences diminished when controlling for age (covariate) using ANCOVA. Nevertheless, Aminoff et al. (1996) did not find significant differences in POpeak, $\dot{V}O_2$ peak and HRpeak between old (57 y) and young (26 y) participants during one- and two-arm cranking exercise. Surprisingly, there were no differences between able-bodied and paraplegic women in the peak values for PO, $\dot{V}O_2$ and \dot{V}_E .

Relationships of RPE with physical and physiological markers of exercise intensity

The present study demonstrated very strong relationships ($R^2 \geq 0.87$) between RPE and physiological (i.e., $\dot{V}O_2$, HR and \dot{V}_E) markers of exercise intensity, regardless of the exercise mode and participant group. In comparison to the relationship between the RPE and the various markers of exercise intensity (i.e., $\dot{V}O_2$, HR, \dot{V}_E) slightly stronger R^2 values were reported when assessing the relationship between PO and RPE, $\dot{V}O_2$ and HR ($R^2 \geq 0.94$). No significant differences were observed between men and women in any of the aforementioned relationships during arm cranking and leg cycling exercise tests. A significantly stronger relationship was also observed between RPE and HR and PO and HR during leg cycling compared to arm cranking exercise in the able-bodied participants (see Table 4.6); which supports previous research which reported stronger correlations between RPE and HR during leg cycling than arm cranking exercise to maximal PO ($r = 0.87$ and $r = 0.76$, respectively; Marais et al., 2001). However, as the difference in the present study only equates to approximately an R^2 of 0.02 to 0.04, this difference between the two exercise modes may be considered negligible. During four sub-maximal exercise tests at 20, 40, 60, and 80% POpeak, Marais et al. (2001) observed similar relationship between RPE and HR in leg cycling and arm cranking ($r = 0.98$ and 0.99, respectively).

Eston and Brodie (1986) reported stronger relationships between RPE and $\dot{V}O_2$ and between RPE and HR for arm cranking exercise ($R^2 = 0.87$ and 0.78 , respectively) compared with leg cycle exercise ($R^2 = 0.65$ and 0.62 , respectively). This difference may be occurred as participants in their study performed both arm and leg exercise at 3 identical absolute exercise intensities (i.e., 49 , ~ 74 and 98 W). In the present study, as participants exercised to maximal functional capacity for both exercise modes, it is not surprising that the strength of the relationship between the RPE and such physiological markers of exercise intensity are similar.

The results demonstrated that when comparing the RPE between able-bodied and paraplegic participants during arm ergometry, participant status only appeared to moderate the relationship between $\dot{V}O_2$: RPE and PO: $\dot{V}O_2$. The study revealed that able-bodied participants reported a significantly stronger relationship between RPE and $\dot{V}O_2$ than their paraplegic counterparts ($R^2 = \sim 0.94$ vs. ~ 0.87 , respectively). There were no significant differences in the strength of the relationships between the RPE and HR and RPE and \dot{V}_E between able-bodied and paraplegic participants. These two indicators of exercise intensity may be more likely to influence the interpretation of physiological cues as $\dot{V}O_2$ is indirectly associated with perceived exertion since it can not be directly (perceptually) monitored by the individual during exercise (Mihevic, 1981; Carton and Rhodes, 1985, Hampson et al., 2001). Ventilation and respiratory rate may be one of the primary physiological mediators of perceived exertion (Horstman et al., 1979; Mihevic, 1981; Robertson, 1982; Carton and Rhodes, 1985; Hampson et al., 2001; Chen et al., 2002).

Comparison of the b coefficient slopes of RPE against PO and %PO

As the study demonstrated some differences in the strength of the physiological relationships with the RPE, it was considered pertinent to assess whether these differences may have been moderated by the study design. Following pilot research different ramp rates were used for the arm cranking and leg cycling exercise tests, for able-bodied and paraplegic participants and for men and women. It was originally

Chapter 4: Perceived Exertion and Physical and Physiological Markers of Exercise Intensity assumed that the differences in the ramp rates may have been an underlying reason as to why there were differences in the RPE and HR relationship during the arm and leg exercise, and perhaps why the RPE and $\dot{V}O_2$ relationship was different for able-bodied and paraplegic participants during arm exercise only.

As expected, when the RPE was expressed in relation to absolute PO, a significantly faster rate of change in the RPE was observed for arm cranking compared to leg cycling exercise and for women compared to men in able-bodied participants. Although gender differences disappeared when the RPE was expressed in proportion to the POpeak, the rate of change in the RPE was significantly faster for the leg cycling ($b = 0.15$) compared to arm cranking exercise ($b = 0.14$). The significantly stronger relationships between the HR and RPE, and PO and HR during leg exercise test may have been due to the faster ramp rate during this exercise protocol. However, when the RPE was expressed against PO and as a proportion of POpeak for able-bodied and paraplegic participants during arm cranking exercise, there were no significant differences in the rate of change in the RPE. It may therefore be assumed that in this example the study design (i.e., different ramp rates) may not have initiated the significantly different relationship between the RPE and $\dot{V}O_2$ for able-bodied and paraplegic participants. Due to these conflicting findings, further research into the effect of ramp rates on the relationship between the RPE and physical and physiological markers of exercise intensity should be assessed in future research studies.

4.5 Conclusion

This study has provided further evidence that the RPE is strongly related to oxygen uptake, heart rate, ventilation and power output during arm cranking and leg cycling. This was evident irrespective of the participants' group or gender. The study demonstrated R^2 values of $R^2 \geq 0.87$ between the RPE and each of these physical and physiological markers of exercise intensity. However, a stronger relationship was observed between the HR and RPE and PO and HR during leg cycling compared to arm cranking. This difference may have been as a result of the different increments in

Chapter 4: Perceived Exertion and Physical and Physiological Markers of Exercise Intensity exercise intensity between the leg cycling and arm cranking exercise. Similarly, a stronger relationship was reported between RPE and $\dot{V}O_2$ and PO and $\dot{V}O_2$ for able-bodied participants compared to paraplegic individuals during arm exercise. This finding appeared not to be influenced by the different increments in exercise intensity during the arm cranking exercise.

As such, future studies could continue to assess the influence of protocol design (i.e., increments in exercise intensity) on the relationship between the RPE and physical and physiological markers of exercise intensity during arm cranking and leg cycling in able-bodied and paraplegic individuals. Furthermore, it may be worthwhile to identify whether the perceptual responses reported during either an *estimation* or *production* procedure provide accurate predictions of $\dot{V}O_2$ peak. To our knowledge, research has only addressed whether trained and untrained able-bodied men and women can accurately predict $\dot{V}O_2$ max from sub-maximal RPE intensities during cycle ergometry (Eston et al., 2005, 2006, 2008; Faulkner and Eston, 2007; Faulkner et al., 2007, 2009; Lambrick et al., 2009). Accordingly, it would be of interest to identify whether able-bodied or individuals with paraplegia may also provide suitable estimates of $\dot{V}O_2$ peak from sub-maximal RPEs during arm ergometry.

We observed very strong linear relationship between the RPE and $\dot{V}O_2$ ($R^2 \geq 0.87$) during arm ergometry for both able-bodied and individuals with paraplegia. Therefore, the aim of the second study was to assess whether sub-maximal RPE and $\dot{V}O_2$ values would provide accurate prediction of $\dot{V}O_2$ peak when extrapolated to the theoretical maximal RPE (RPE20). It will also be of interest to assess whether the accuracy of prediction of $\dot{V}O_2$ peak would be moderated by participants' group and/or gender.

Chapter five

Study 2

Prediction of peak oxygen uptake from ratings of perceived exertion during arm cranking, ramp exercise test in able-bodied and paraplegic individuals

Data from this chapter have contributed to:

Publication:

Harran Al-Rahamneh, James Faulkner, Christopher Byrne and Roger Eston (2010). Prediction of peak oxygen uptake from ratings of perceived exertion during arm exercise in able-bodied and persons with poliomyelitis. *Spinal Cord*, 1-5.

Oral presentation:

Harran Al-Rahamneh, James Faulkner, Christopher Byrne and Roger Eston. Prediction of peak oxygen uptake using rating of perceived exertion during arm cranking exercise in able-bodied and individuals with poliomyelitis. BASES Student Conference 2010, Aberystwyth, UK.

5.1 Introduction

Maximal oxygen uptake ($\dot{V}O_2\text{max}$) is the maximum rate at which an individual can take up and utilize oxygen during exercise involving large muscle groups (Åstrand et al., 2003). Although a valuable indicator of cardiorespiratory endurance capacity and aerobic fitness (Noonan and Dean, 2000; Laukkanen et al., 2001; Wilmore and Costill, 2004; ACSM, 2010), the measurement of $\dot{V}O_2\text{max}$ is expensive, time consuming and requires a high degree of compliance from the individual involved (Eston et al., 2009). There are also practical concerns when conducting exhaustive exercise tests with non-athletic, elderly or patient populations (Noble, 1982). Accordingly, for reasons of cost, safety and time, it is sometimes preferable to estimate $\dot{V}O_2\text{max}$ using sub-maximal exercise procedures (Noble, 1982). On the basis of strong linear relationships between $\dot{V}O_2$ and heart rate, e.g., Tolfrey et al., 2001; Goosey-Tolfrey and Tolfrey, 2004, and between $\dot{V}O_2$ and the Borg 6-20 Rating of Perceived Exertion (RPE) Scale (Borg, 1970, 1998, Table 2.1), e.g., Eston et al., 2005, 2006, it is possible to predict $\dot{V}O_2\text{max}$ from sub-maximal HR and/or the RPE (Morgan and Borg, 1976; Noble et al., 1981; Faulkner and Eston, 2007; Faulkner et al., 2007).

Recent research has shown that $\dot{V}O_2$ values corresponding with sub-maximal RPE may be used to predict $\dot{V}O_2\text{max}$ when extrapolated to RPE20 on the Borg 6-20 Scale (Faulkner and Eston, 2007; Faulkner et al., 2007, 2009; Coquart et al., 2009; Lambrick et al., 2009). To date, this has only been demonstrated during cycle exercise with able-bodied, active, sedentary and obese participants (Faulkner and Eston, 2007; Coquart et al., 2009; Faulkner et al., 2009; Lambrick et al., 2009). More accurate estimates of $\dot{V}O_2\text{max}$ have been shown from higher perceptual intensities (i.e., RPEs prior to and including RPE17) as reflected by narrower limits of agreement (LoA) and higher intra-class correlations coefficient (ICC) between measured and predicted $\dot{V}O_2\text{max}$ (Faulkner and Eston, 2007). However, recent studies with low-fit men and women have shown accurate predictions of $\dot{V}O_2\text{max}$ from a single sub-maximal

exercise test that utilises a perceptual range up to and including RPE13 (Faulkner and Eston, 2007; Faulkner et al., 2009; Lambrick et al., 2009). The application of a lower perceptual range may be more appropriate for sedentary individuals or certain clinical populations as it may minimise the duration of the test, and ensure safe exercise performance (Faulkner and Eston, 2007; Coquart et al., 2009; Faulkner et al., 2009; Lambrick et al., 2009). The RPE range between 12 to 15 equates to approximately 50 – 70% $\dot{V}O_2$ peak in healthy able-bodied and paraplegic individuals (Parfitt and Eston, 1996; Faulkner et al., 2007; Goosey-Tolfrey et al., 2010).

It has been shown that RPE may provide estimates of $\dot{V}O_2$ max that are as accurate as those elicited from age-predicted maximal heart rate in able-bodied participants (Lambrick et al., 2009). However, the utility of age-predicted maximal heart rate may be limited in high-lesion paraplegic persons (i.e., above T6), as such individuals often exhibit abnormal heart rate, hemodynamic (i.e., blood distribution) and metabolic responses during exercise, most likely due to a loss of sympathetic innervation due to an impaired autonomic and motor nervous system (Lockette and Keyes, 1994; Janssen and Hopman, 2005).

As previous research has established the efficacy of using sub-maximal RPE to predict $\dot{V}O_2$ peak during cycle ergometry with able-bodied participants, the purpose of this study was to assess the validity of this method for arm cranking exercise in both able-bodied and paraplegic participants. We hypothesized that sub-maximal RPE values reported during arm cranking exercise would provide an accurate prediction of $\dot{V}O_2$ peak in both groups irrespective of gender.

5.2 Methods

Participants

Sixteen able-bodied men and women and 15 men and women with paraplegia, volunteered to take part in the study (Table 5.1). Individuals with paraplegia had flaccid paralysis of the lower limbs. Participation in the study was dependent upon the

participants providing written informed consent, being under the age of 45 years, no prior experience with arm cranking exercise or perceptual scaling, and no complications in the upper body, cardiovascular and cardiorespiratory systems and the torso. All participants had their blood pressure measured (Accoson, London, England) prior to exercise participation. The study was conducted following institutional ethics approval from the Faculty of Physical Education at the University of Jordan. For more details please see section (*4.3 methods, participants*).

Table 5.1: Participant characteristics and relative disability descriptions and mean \pm SD for groups

Participant	Gender	Age (years)	Height (cm)	Body mass (kg)	Type of injury
Para 1	Male	39.7	158	54.6	Polio
Para 2	Male	38.0	161	43.2	Polio
Para 3	Male	28.2	179	93.1	Polio
Para 4	Male	39.1	165	69.1	Polio
Para 5	Male	34.5	187	87.5	Polio
Para 6	Male	31.3	162	70.0	Polio
Para 7	Male	35.2	162	73.5	Polio
Para 8	Male	32.0	168	71.0	Polio
Para 9	Female	29.5	151	58.9	Polio
Para 10	Female	33.0	150	34.5	Polio
Para 11	Female	39.8	147	71.8	Polio
Para 12	Female	29.2	144	50.0	Polio
Para 13	Female	39.0	145	55.7	Polio
Para 14	Female	33.1	140	52.0	Polio
Para 15	Female	31.4	155	63.1	Polio
Paraplegic men	-	$35.0 \pm 4.0^*$	$168.0 \pm 10.1^*$	71.0 ± 16.2	-
Able-bodied men	-	20.3 ± 0.5	176.2 ± 6.0	70.4 ± 17.1	-
Paraplegic women	-	$33.4 \pm 5.0^\circ$	$147.4 \pm 5.0^\circ$	55.1 ± 12.0	-
Able-bodied women	-	20.8 ± 0.8	162.0 ± 6.4	56.4 ± 7.6	-

* Significant difference between able-bodied and paraplegic men $P < 0.05$

° Significant difference between able-bodied and paraplegic women $P < 0.05$

Procedures

All participants performed a single arm cranking ramp exercise test designed to establish peak oxygen uptake ($\dot{V}O_2\text{peak}$) on the same Lode arm ergometer (Lode, B.V. Medical Technology, Groningen, Netherlands). The resistance on the ergometer was

manipulated using the *Lode Workload Programmer*, accurate to ± 1 W, which was independent of pedal cadence. In accordance with previous research (Schwade et al., 1977; Raymond et al., 1997; Kang et al., 1999), participants maintained a cadence of 50 rpm throughout the exercise tests. For more details please see section (4.3 *methods, procedures*).

Measures

Borg 6-20 RPE scale

Please see section (3.2 *Borg 6-20 RPE scale*).

Graded exercise test to establish $\dot{V} O_2$ peak

The graded exercise test (GXT) utilised a ramp protocol. Lambrick et al. (2009) postulated that the continuous change in workload may induce a more frequent appraisal of the feelings of exertion, thus facilitating more accurate estimates of $\dot{V} O_2$ peak in comparison to step-wise protocols. In accordance with the ACSM guidelines, and following 4 minutes warm up at 0 W, the work rate increased by 15 $W \cdot min^{-1}$ and 6 $W \cdot min^{-1}$ for able-bodied men and women, respectively. A 9 $W \cdot min^{-1}$ increment for men with paraplegia, and 6 $W \cdot min^{-1}$ increment for women with paraplegia, was considered to be more appropriate. During the last 20 s of each minute, and at the completion of the exercise test, participant's estimated their overall RPE. For more details see section (4.3 *methods, measures, arm cranking ramp exercise test*).

Data analysis

Prediction of $\dot{V} O_2$ peak from RPE 13, 15 and 17

The mean $\dot{V} O_2$ recorded during the last 20 s of each minute was regressed against the corresponding RPE in a linear regression analysis for each participant. The corresponding individual coefficient of determination (R squared; R^2) was converted to an appropriate Fisher Zr transformation value to approximate the normality of the sampling distribution (Thomas et al., 2005). Where an RPE of 13, 15 or 17 had not been reported during the exercise test, linear regression analysis was used to

determine the corresponding sub-maximal $\dot{V}O_2$ value ($\dot{V}O_2 = b(RPE\ 13,\ 15\ or\ 17) + c$; Vincent, 1999). Individual linear regression analyses using the sub-maximal $\dot{V}O_2$ values elicited prior to and including an RPE 13, 15 and 17 were then extrapolated to RPE20 on the Borg 6-20 RPE Scale to predict $\dot{V}O_{2\text{peak}}$ (Figure 5.1).

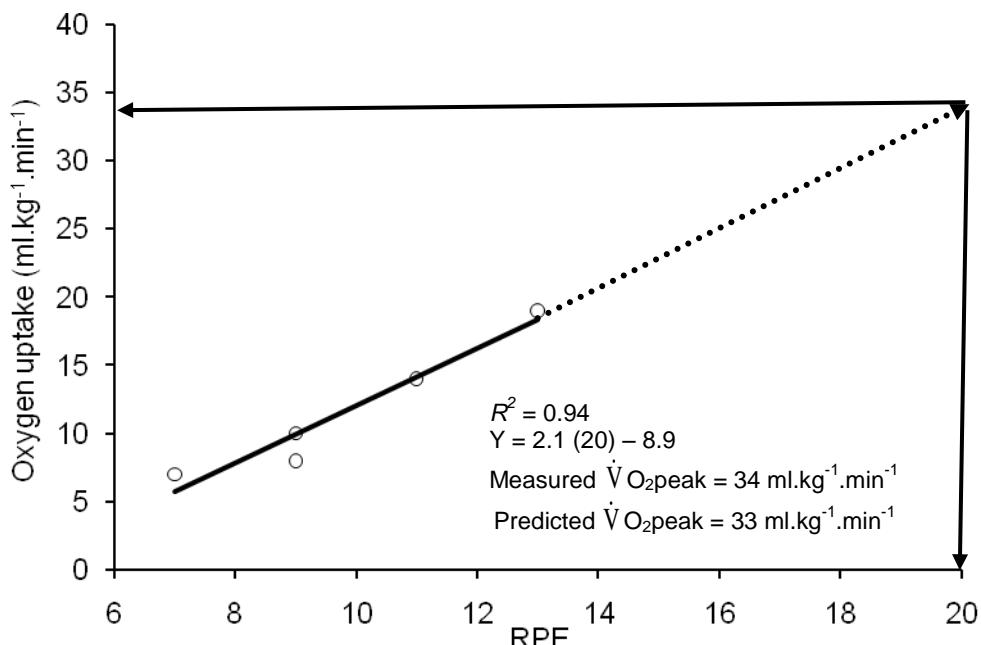


Figure 5.1: Prediction of $\dot{V}O_{2\text{peak}}$ from RPEs up to and including RPE13 when extrapolated to RPE20 from a ramp exercise test for an able-bodied participant

A three factor ANOVA (Method; measured $\dot{V}O_{2\text{peak}}$, predicted $\dot{V}O_{2\text{peak}}$ from RPEs up to and including RPE13, 15 and 17 x Participants' group; able-bodied and paraplegic x Gender; men and women) compared measured and predicted $\dot{V}O_{2\text{peak}}$, and assessed whether gender and/or participants' group moderated these findings. The Mauchly's test was used to confirm the assumptions of sphericity for repeated measures ANOVA (Field, 2009). Where this was not confirmed, the Greenhouse-Geisser correction factor was applied to correct the degrees of freedom (Field, 2009). Tukey's post hoc tests were used to follow up significant interactions. Alpha was set at P 0.05 and adjusted accordingly. All data were analysed using SPSS version 16.0 for windows.

Analysis of the consistency of the predictions in $\dot{V} O_2$ peak

Bland and Altman, (1986) introduced a new method to assess the validity of a new measure against an established one. This technique is called a Limits of Agreement (LoA) analysis. This method compares the difference between the two measures (Y axis) against the mean of the two measures (X axis). The method was originally invented to advise researchers to avoid the misuse of the correlation coefficient analysis when assessing validity (Hopkins, 2004). Although two variables may be highly correlated there may yet be substantial difference in the scores of the two variables (Hopkins, 2004). Bland and Altman, (1986) and Nevill and Atkinson, (1997) recommended that data should be checked for heteroscedastic error (i.e., the larger mean of the two measures corresponds to a higher difference between the two measures) before assessing LoA analysis. This is done by conducting a correlation coefficient analysis on the difference between the two measures and the mean of the two measures.

Although the paper by Bland and Altman, (1986) has been cited more than 9000 times, there is a relatively current debate regarding the use of LoA to assess validity between two measures (e.g., Hopkins, 2004; Hopkins et al., 2009). Alternatively, Hopkins et al. (2009) advised researchers to use linear regression instead of LoA when assessing validity. These authors based their point of view on: 1) LoA does not provide useful information when a new method is compared against an imprecise established one. However, regression validity analysis can be combined with published regression equations of the imprecise measure to estimate an accurate regression analysis for the new method. 2) Regression analysis can be used for all validity studies; whereas LoA can be used in method-comparison studies where both measures have the same units. 3) Data usually have more than one source of random error which can be referred to as variances in the linear model. These variances are combined and expressed as standard error of measurement in regression.

The debate is ongoing regarding the use of LoA analysis to assess the validity of a new measure against an established one. With regard to the current studies in this

thesis, there are two methods only (i.e., measured $\dot{V}\text{O}_{2\text{peak}}$ versus predicted $\dot{V}\text{O}_{2\text{peak}}$) to be compared. Therefore, Bland and Altman, (1986) 95% LoA analysis quantified the agreement (bias $\pm 1.96 \times \text{SD}$ difference) between measured and predicted $\dot{V}\text{O}_{2\text{peak}}$ for each RPE range. Intraclass correlation coefficient was also used to quantify the relationship between predicted and measured values.

5.3 Results

Descriptive statistics

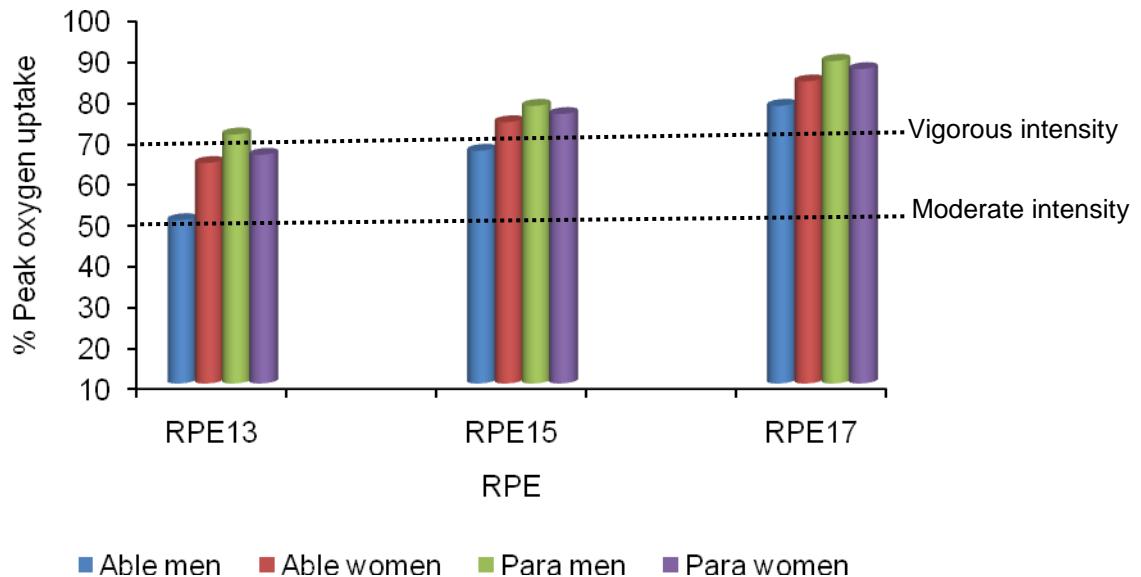
Peak physiological and RPE values are shown in Table 5.2. Individual linear regression analyses of individual RPE and $\dot{V}\text{O}_2$ values reported throughout the exercise test yielded an average R^2 value of 0.91. Similar R^2 values were observed for RPE and $\dot{V}\text{O}_2$ relationships reported prior to and including an RPE 13, 15 and 17 (all $R^2 \geq 0.87$). The $\dot{V}\text{O}_2$ and % $\dot{V}\text{O}_{2\text{peak}}$ observed at RPE 13, 15 and 17 are presented in Table 5.3. Figure 5.2 shows % $\dot{V}\text{O}_{2\text{peak}}$ at RPE13, 15 and 17 for both groups.

Table 5.2: Peak physiological and perceptual values observed at the termination of the arm cranking test for able-bodied and paraplegic participants. Values are (mean \pm SD).

Group/Gender	$\dot{V}\text{O}_{2\text{peak}}$ (L·min $^{-1}$)	$\dot{V}\text{O}_{2\text{peak}}$ (ml·kg $^{-1}$ ·min $^{-1}$)	HRpeak (b·min $^{-1}$)	RER	\dot{V}_{Epeak} (L·min $^{-1}$)	RPE (overall)
Able-bodied men	1.96 \pm 0.32	28 \pm 5	163 \pm 19	1.08 \pm 0.07	73 \pm 17	19.6 \pm 0.7
Able-bodied women	1.07 \pm 0.19	19 \pm 2	161 \pm 17	1.06 \pm 0.08	41 \pm 5	19.6 \pm 0.9
Paraplegic men	1.65 \pm 0.40	24 \pm 4	165 \pm 14	1.05 \pm 0.05	65 \pm 18	19.4 \pm 1.1
Paraplegic women	1.01 \pm 0.14	19 \pm 4	155 \pm 20	1.01 \pm 0.09	43 \pm 8	18.7 \pm 1.1

Table 5.3: The $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$) values and % $\dot{V}O_2$ peak observed at RPE 13, 15 and 17 for both able-bodied and paraplegic individuals. Values are (mean \pm SD).

Group/Gender	RPE 13	RPE 15	RPE 17
Able-bodied men	14 ± 6 (50 ± 14)*	19 ± 6 (67 ± 12)	23 ± 6 (78 ± 11)
Able-bodied women	12 ± 1 (64 ± 5)	14 ± 2 (74 ± 7)	16 ± 3 (84 ± 10)
Paraplegic men	17 ± 7 (71 ± 25)°	19 ± 5 (78 ± 19)	21 ± 5 (89 ± 15)
Paraplegic women	13 ± 7 (66 ± 23)	15 ± 7 (76 ± 22)	17 ± 6 (87 ± 18)

* Significant difference between men and women of able-bodied group $P < 0.05$ ° Significant difference between able-bodied and paraplegic men $P < 0.05$ **Figure 5.2:** Proportions of $\dot{V}O_2$ peak observed at RPE13, 15 and 17 for able-bodied and paraplegic individuals

Independent-sample t-tests revealed that able-bodied women exercised at significantly higher % $\dot{V}O_2$ peak at RPE13 compared to their men counterparts ($t_{(14)} = 2.6, P < 0.05$). No significant differences were observed between able-bodied men and women in % $\dot{V}O_2$ peak at RPE15 and 17 (all $P > 0.05$). Similar analysis revealed no significant difference between paraplegic men and women in % $\dot{V}O_2$ peak observed at RPE13, 15 and 17 (all $P > 0.05$). Further analysis revealed no significant difference between able-bodied and paraplegic women in % $\dot{V}O_2$ peak observed at RPE13, 15 and 17 (all $P > 0.05$). Finally, paraplegic men exercised at significantly higher % $\dot{V}O_2$ peak at RPE13 ($t_{(15)} = 2.3, P < 0.05$) compared to their able-bodied counterparts. Proportions

of $\dot{V}O_2$ peak for able-bodied and paraplegic individuals can be seen from Table 5.3 and Figure 5.2.

Prediction of $\dot{V}O_2$ peak from RPE13, 15 and 17

There were no significant differences between measured and predicted $\dot{V}O_2$ peak from sub-maximal RPE values prior to and including an RPE 13, 15 and 17 ($F_{(1,9,50.6)} = 0.8, P > 0.05$). The $\dot{V}O_2$ peak was significantly higher in men, regardless of group ($F_{(1,27)} = 5.5, P < 0.05$). There was a significant interaction of group x method on $\dot{V}O_2$ peak ($F_{(1,9,50.6)} = 5.1, P < 0.05$). Post hoc analysis using Tukey's Honestly Significant Difference (HSD) test showed that predicted $\dot{V}O_2$ peak from RPEs up to and including RPE13 was significantly higher ($P < 0.05$) for paraplegic individuals. There was no significant difference between groups in $\dot{V}O_2$ peak ($F_{(1,27)} = 0.0, P > 0.05$), no significant gender x group interaction ($F_{(1,27)} = 0.1, P > 0.05$) and no significant interactions for gender x method ($F_{(1,9,50.6)} = 1.4, P > 0.05$) or for gender x group x method on $\dot{V}O_2$ peak ($F_{(1,9,50.6)} = 0.8, P > 0.05$). Measured and predicted $\dot{V}O_2$ peak from the three RPE ranges are presented in Table 5.4.

Table 5.4: Measured and predicted $\dot{V}O_2$ peak ($ml.kg^{-1}min^{-1}$) for able-bodied and paraplegic participants. Values are (mean \pm SD).

Group/Gender	Measured	$\dot{V}O_2$peak from	$\dot{V}O_2$peak from	$\dot{V}O_2$peak from
	$\dot{V}O_2$ peak	RPEs up to 13	RPEs up to 15	RPEs up to 17
Able-bodied men	28 ± 5	23 ± 10	27 ± 9	27 ± 8
Able-bodied women	19 ± 2	20 ± 5	20 ± 5	20 ± 5
Paraplegic men	24 ± 4	$29 \pm 11^*$	26 ± 8	26 ± 7
Paraplegic women	19 ± 4	$25 \pm 14^*$	20 ± 10	20 ± 9
Able-bodied persons	24 ± 6	22 ± 8	24 ± 8	24 ± 8
Paraplegic persons	21 ± 5	$27 \pm 12^*$	23 ± 9	23 ± 8

* Significant difference between measured and predicted $\dot{V}O_2$ peak $P < 0.05$

Limits of agreement and intraclass correlation coefficients

The 95% LoA were narrower in the able-bodied group (bias \pm $1.96 \times$ SD difference) for RPE 13, 15 and 17 (-3 ± 14 , -1 ± 10 and $0 \pm 8 ml.kg^{-1}.min^{-1}$, respectively)

vs. the paraplegic participants (6 ± 19 , 2 ± 12 and $1 \pm 9 \text{ ml}\cdot\text{kg}^{-1} \text{ min}^{-1}$, respectively).

The reliability of predicting $\dot{V}\text{O}_2\text{peak}$ was also greater in the able-bodied participants (ICCs at RPE 13, 15 and 17 were 0.70, 0.85, and 0.91 vs. 0.61, 0.78 and 0.83, for the able-bodied and paraplegic participants, respectively).

5.4 Discussion

This study was conducted to investigate whether sub-maximal RPE and $\dot{V}\text{O}_2$ values elicited during arm cranking exercise with able-bodied and paraplegic participants could accurately predict $\dot{V}\text{O}_2\text{peak}$ when these values were extrapolated to RPE20. The strong relationship between the Borg 6-20 RPE scale and $\dot{V}\text{O}_2$ was confirmed in the present study with a high mean correlation of $R^2 = 0.91$ across the duration of the exercise test. Similar correlations were observed for the relationship between RPE and $\dot{V}\text{O}_2$ up to and including an RPE 13, 15 and 17 for both able-bodied participants and individuals with paraplegia ($R^2 \geq 0.87$).

The strong relationship between the RPE and $\dot{V}\text{O}_2$ supports previous research that has utilised the RPE during arm cranking exercise in individuals with spinal cord injury (Hicks et al., 2003; Goosey-Tolfrey et al., 2010), but do not concur with the suggestion that the RPE may not be a valid means of assessing or regulating exercise intensity in individuals with spinal cord injury and spinal cord disease (Jacobs et al., 1997; Horemans et al., 2004; Gylfadottir et al., 2006; Lewis et al., 2007). The equivocal observations may be attributed to the different exercise protocols utilised in these studies. Lewis et al. (2007) employed a discontinuous arm cranking exercise test to examine the relationship between perceived exertion and physiologic indicators of stress, whereas the current study employed a ramp protocol to determine peak functional capacity.

The ACSM (2010) recommends that a combination of moderate intensity (i.e., 40% - < 60% of $\dot{V}\text{O}_2$ reserve) and vigorous intensity (i.e., > 60% of $\dot{V}\text{O}_2$ reserve) as a suitable exercise intensity range to enhance cardiorespiratory fitness. For each of the

perceptual ranges, the mean relative $\dot{V}O_2$ (%) was similar for paraplegic men and women and able-bodied women. Participants elicited a mean $\dot{V}O_2$ of 64% to 71% when exercising up to and including an RPE13. These values are similar to those observed during a ramp exercise tests on a cycle ergometer (Lambrick et al., 2009). Even though these participants exercised at a similar physiological intensity, less accurate estimates of $\dot{V}O_{2\text{peak}}$ were observed for individuals with paraplegia. Although paraplegic participants will be more familiar with arm exercise, as it is the only mode of exercise which can be used for training and mobilization, they may have underestimated the RPE at a given work rate. This will have led to a higher $\dot{V}O_{2\text{peak}}$. This was particularly evident for RPEs prior to and including RPE13 when extrapolated to RPE20.

In accordance with previous research, narrower LoA and stronger ICC were demonstrated between measured and predicted $\dot{V}O_{2\text{peak}}$ from the higher perceptual ranges (Faulkner and Eston, 2007). The LoA for the predictions of $\dot{V}O_{2\text{peak}}$ from the lower perceptual range (RPE13) for the able-bodied participants ($-3 \pm 14 \text{ ml}\cdot\text{kg}^{-1}\text{min}^{-1}$) are higher than those reported by Lambrick et al. (2009) during cycle exercise ($-0 \pm 6 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$). The lower intraclass correlation coefficient for these data further substantiates this observation ($R = 0.70$ and $R = 0.94$, respectively). This may reflect that able-bodied participants are not as familiar with arm cranking exercise compared to leg cycling.

5.5 Conclusion

Our findings demonstrate that $\dot{V}O_{2\text{peak}}$ may be estimated with reasonable accuracy from a single, continuous ramp exercise test in able-bodied participants during arm exercise when extrapolated to RPE20. The accuracy of estimating $\dot{V}O_{2\text{peak}}$ is improved when it is predicted from the higher perceptual ranges (i.e., RPEs up to and including RPE15 and 17) regardless of participants' group. However, there was considerable variability in the consistency of the predictions of $\dot{V}O_{2\text{peak}}$ particularly for the paraplegic participants. Furthermore, the prediction of $\dot{V}O_{2\text{peak}}$ from

RPEs up to and including RPE13 was significantly higher in the paraplegic participants. It is unknown whether a period of practice in the reporting of RPE during arm cranking exercise would improve the prediction of $\dot{V}O_2$ peak.

We observed large limits of agreement and moderate intraclass correlation coefficient between measured and predicted $\dot{V}O_2$ peak from a single ramp exercise test during arm cranking especially for paraplegic individuals. In addition, predicted $\dot{V}O_2$ peak from RPEs prior to and including RPE13 when extrapolated to RPE20 was significantly higher than measured $\dot{V}O_2$ peak for paraplegic persons. Therefore, the aim of the next study was to assess the accuracy of predicting $\dot{V}O_2$ peak from sub-maximal RPE values when extrapolated to RPE20 using different protocols (i.e., ramp exercise test $15\text{ W}\cdot\text{min}^{-1}$) and graded exercise test (15 W every 2 minutes) in able-bodied and paraplegic individuals.

Chapter six

Study 3

Prediction of peak oxygen uptake from the ratings of perceived exertion during a graded and ramp exercise test in able-bodied and persons with paraplegia

Data from this chapter have contributed to:

Publication:

Harran Al-Rahamneh and Roger Eston. Prediction of maximal oxygen uptake from the ratings of perceived exertion during a graded and ramp exercise test in able-bodied and persons with paraplegia. *Archives of Physical Medicine and Rehabilitation*.

6.1 Introduction

The Borg 6-20 Ratings of Perceived Exertion (RPE) Scale (Borg, 1998, Table 2.1) is frequently used to assess overall and localized perceived effort during exercise. It has been repeatedly shown that there is a very strong relationship between the RPE and power output (PO), oxygen uptake ($\dot{V}O_2$), heart rate (HR) and ventilation (\dot{V}_E) during leg cycling (Demura and Nagasawa, 2003; Faulkner and Eston, 2007; Lambrick et al., 2009) running on a treadmill (Eston et al., 1987; Davis et al., 2008) and during arm ergometry (Eston and Brodie, 1986; Borg et al., 1987). On the basis of the strong linear relationship between the RPE and $\dot{V}O_2$, the RPE has been used to predict maximal oxygen uptake ($\dot{V}O_{2\max}$) during leg cycling in healthy able-bodied participants (Faulkner and Eston, 2007; Lambrick et al., 2009; Faulkner et al., 2009), obese women (Coquart et al., 2009) and healthy young females during treadmill running (Davies et al., 2008). However, to our knowledge, there is no research which has assessed the utility of sub-maximal RPE elicited during a graded exercise test and a ramp exercise test to predict $\dot{V}O_2\text{peak}$ during arm exercise in able-bodied and individuals with paraplegia.

The efficacy of using the RPE to regulate and prescribe exercise intensity in individuals with paraplegia is not clear. Lewis et al. (2007) observed a poor relationship between the RPE and $\dot{V}O_2$ during a discontinuous incremental arm exercise test. Similarly, Jacobs et al. (1997) recommended that HR but not RPE should be used to control exercise intensity in individuals with paraplegia using functional neuromuscular stimulation. However, in a recent study by Goosey-Tolfrey et al. (2010) no significant differences were observed in HR, $\dot{V}O_2$ and blood lactate level between imposed power based on 50% (moderate) and 70% $\dot{V}O_2\text{peak}$ (vigorous) and RPE-regulated exercise intensities. In accordance with Goosey-Tolfrey et al. (2010), Müller et al. (2004) observed no significant difference in the reproducibility of the RPE during 5 x 1500 m exercise tests on two different occasions. Furthermore, in the first study (chapter 4) we

observed a strong linear relationship between the RPE and $\dot{V}O_2$ ($R^2 \geq 0.87$) during arm cranking using a ramp exercise test to volitional exhaustion in paraplegic individuals.

Maximal exercise testing is not recommended for some sedentary and clinical populations (Wilmore et al., 1986; ACSM, 2010). In addition, depression is common in individuals with paraplegia (Birk, 2009; Figoni, 2009) which may in turn affect their motivation to perform a maximal exercise test. Therefore, the aim of this study was to assess the accuracy of predicting $\dot{V}O_2$ peak from a Graded Exercise Test (GXT) and a ramp exercise test using sub-maximal RPE. We hypothesized that sub-maximal RPE and $\dot{V}O_2$ values would provide an acceptable prediction of $\dot{V}O_2$ peak when extrapolated to RPE20 and that this would not be moderated by the exercise test (i.e., GXT and ramp exercise test) or participants' group (i.e., able-bodied and paraplegic).

6.2 Methods

Participants

Thirteen able-bodied men (mean \pm SD, 27.2 ± 4.3 y, 173.5 ± 4.9 cm, 74.5 ± 11.8 kg) and 12 men with paraplegia (mean \pm SD, 31.1 ± 5.7 y, 170.5 ± 5.4 cm, 63.5 ± 11.5 kg) volunteered to take part in the study. Able-bodied participants were sport sciences students studying at the University of Exeter who were healthy and free from illnesses and pre-existing injuries. Regarding persons with paraplegia, six of them had lower limbs paralysis as a result of poliomyelitis infection, whereas the other six had spinal cord injuries (SCI) with neurological levels at T6 and below. Able-bodied participants were physically active (> 3 h per week) but not arm trained (e.g., swimmer). Persons with paraplegia were physically active (> 3 h per week) and participated in such sports as basketball, table tennis, weightlifting and wheelchair racing at both professional and recreational levels. Please see section (3.1 *Measurement of height and body mass (for all the studies)*) for more details about how height and body mass were measured.

This study was conducted with joint institutional ethics approval from the Faculty of Physical Education at the University of Jordan and the School of Sport and Health Sciences at the University of Exeter. The exercise tests for the able-bodied and paraplegic participants were conducted at the University of Exeter and the University of Jordan, respectively.

Procedures

Each participant (i.e., able-bodied and paraplegic) performed two exercise tests. A ramp exercise test was performed to establish peak functional capacity (see section (*3.5 ramp exercise test*) for more details). A GXT was also performed to assess whether there was a difference in peak values (i.e., P_{Opeak}, $\dot{V}O_2$ _{peak} and HR_{peak}) between the GXT and the ramp exercise test (please see section (*3.6 graded exercise test*) for more details). These two exercise tests were conducted in counterbalanced order to avoid an ordering effect. These exercise tests were also separated by 48 h to allow enough recovery time. All participants were asked to avoid moderate and heavy exercise intensities prior to and between the exercise tests. All exercise tests were performed on the same Lode arm ergometer. Expired air was collected during both exercise tests. See sections (*3.3 gas analysis and 3.4 arm ergometry*) for more details about gas analysis and the arm ergometry.

Measures

Borg 6-20 RPE Scale

Participants reported their RPEo and RPEp at the completion of the exercise tests and in the remaining 20 s of each minute and each stage during the ramp exercise test and the GXT, respectively. Please see section (*3.2 Borg 6-20 RPE Scale*) for more details. In this study we were interested in assessing both overall RPE and peripheral RPE. That was deemed appropriate due to the fact that smaller muscle mass are activated during arm crank exercise. In other words, more afferent feedback from muscles and joints compared to the central signal (breathing and heart rate) go to the brain.

Data analysis

A series of independent sample t-tests revealed no significant differences between individuals with polio and those with SCI in any of the physiological variables (all $P > 0.05$). Therefore, they were combined in one group (i.e., paraplegic individuals) for the following analysis.

A series of two factor ANOVAs (Test; GXT and ramp x Group; able-bodied and paraplegic) were used to assess whether there was a difference in the peak physiological, physical and perceptual values (i.e., HR, $\dot{V}O_2$, PO and RPE) observed at the termination of the GXT and the ramp exercise test and between groups. A series of paired sample t-tests were used to compare whether there was a significant difference between RPEo and RPEp reported at the termination of the GXT and the ramp exercise test for able-bodied and paraplegic individuals.

Comparison of measured vs. predicted $\dot{V}O_2$ peak

The mean $\dot{V}O_2$ recorded during the last 20 s of each minute during the ramp exercise test and during the last 20 s of each stage during the GXT were regressed against the corresponding peripheral RPE in a linear regression analysis for each participant. The corresponding individual coefficient of determination (R squared; R^2) was converted to an appropriate Fisher Zr transformation value to approximate the normality of the sampling distribution (Thomas et al., 2005). Where a peripheral RPE of 13, 15 or 17 had not been reported during either the GXT or the ramp exercise test, linear regression analysis was used to determine the corresponding sub-maximal $\dot{V}O_2$ value ($\dot{V}O_2 = b(RPE\ 13, 15\ or\ 17) + c$). Individual linear regression analyses using the sub-maximal $\dot{V}O_2$ values elicited prior to and including a peripheral RPE 13, 15 and 17 were then extrapolated to the theoretical maximal RPE (RPE20) on the Borg 6-20 RPE Scale to predict $\dot{V}O_2$ peak (Figure 6.1).

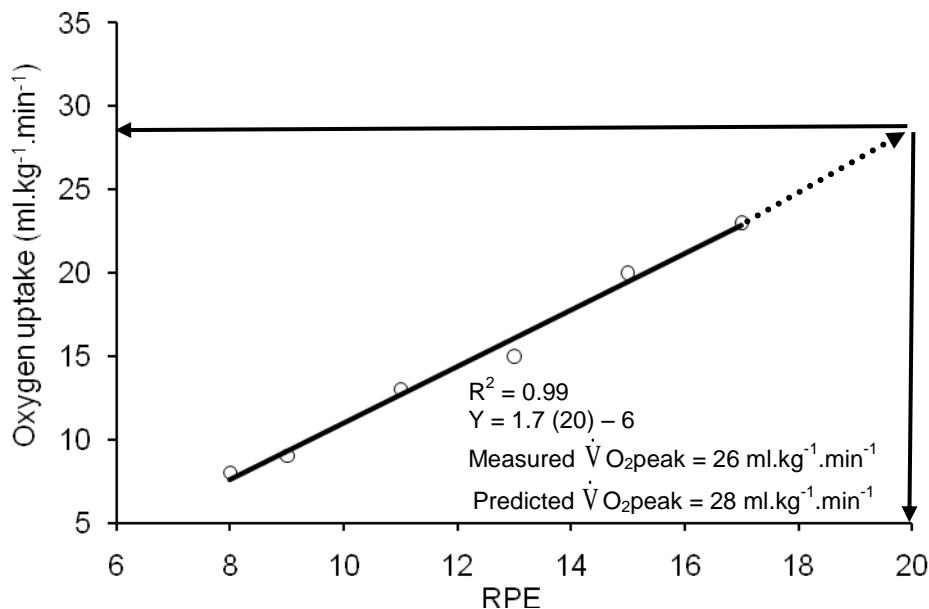


Figure 6.1: Prediction of $\dot{V}O_2$ peak from RPEs prior to and including RPE 17 when extrapolated to RPE20 from a ramp exercise test for a paraplegic individual

A three factor ANOVA (Test; GXT and ramp; Method; measured $\dot{V}O_2$ peak, predicted $\dot{V}O_2$ peak from RPEs prior to and including RPE 13, 15 and 17; Group; able-bodied and paraplegic) was used to compare measured versus predicted $\dot{V}O_2$ peak and whether that was moderated by the form of exercise test (i.e., GXT and ramp) and/or participants' group. The assumptions of sphericity for all tests were checked using the Mauchly' test; where sphericity assumptions were not confirmed, the Greenhouse-Geisser epsilon was used to correct the degrees of freedom (Winter et al., 2001; Field, 2009). Alpha was set at P 0.05 and adjusted accordingly. All data were analysed using SPSS for windows version 16.

Analysis of the consistency of the predictions in $\dot{V}O_2$ peak

A Bland and Altman, (1986) 95% LoA analysis quantified the agreement (bias \pm $1.96 \times SD$ difference) between measured and predicted $\dot{V}O_2$ peak for each RPE range. In accordance with recommendations (Bland and Altman, 1986; Nevill and Atkinson, 1997), data were checked for heteroscedasticity by conducting a Pearson product-moment correlation analysis on the difference between the measured and predicted

$\dot{V}O_2$ peak scores and the average of the two measurement scores, prior to LoA analysis. Intraclass correlation coefficient was also used to quantify the relationship between predicted and measured $\dot{V}O_2$ peak values.

6.3 Results

Descriptive statistics of the peak values observed at the completion of the exercise tests

The peak physiological (i.e., $\dot{V}O_2$ peak and HRpeak), perceptual (i.e., RPEo and RPEp) and physical (i.e., PO) values observed at the termination of the GXT and the ramp exercise test are presented in Table 6.1.

Table 6.1: Peak physiological, physical and perceptual values observed at the completion of the GXT and the ramp exercise test for able-bodied and paraplegic individuals. Values are (mean \pm SD).

Exercise	Group	POpeak (W)	$\dot{V}O_2$ peak (L.min $^{-1}$)	$\dot{V}O_2$ peak (ml.kg $^{-1}$.min $^{-1}$)	HRpeak (b.min $^{-1}$)	RPEo	RPEp	Time to exhaustion (min)
GXT	Able-bodied	118 \pm 16 ⁺ *	2.51 \pm 0.41	35 \pm 7*	167 \pm 14*	17.9 \pm 1.6	19.7 \pm 0.6°	13.4 \pm 1.9
	Paraplegic	90 \pm 19*	1.96 \pm 0.42	31 \pm 6*	177 \pm 15*	18.7 \pm 0.9	19.4 \pm 0.7°	9.7 \pm 2.7
Ramp	Able-bodied	136 \pm 14 ⁺	2.38 \pm 0.35	33 \pm 6	156 \pm 14	17.5 \pm 1.5	19.6 \pm 0.7°	9.1 \pm 1.0
	Paraplegic	105 \pm 20	1.84 \pm 0.42	29 \pm 5	168 \pm 17	18.5 \pm 1.0	19.6 \pm 0.5°	7.0 \pm 1.4

* Significant difference between GXT and the ramp exercise test $P < 0.05$

⁺ Significant difference between able-bodied and paraplegic persons $P < 0.05$

° Significant difference between RPEo and RPEp $P < 0.05$

Participants achieved a significantly higher $\dot{V}O_2$ peak during the GXT compared to the ramp exercise test ($F_{(1, 23)} = 19.9, P < 0.001$). There was no significant difference in $\dot{V}O_2$ peak between the able-bodied participants and paraplegic persons ($F_{(1, 23)} = 2.0, P > 0.05$) and no significant test x group interaction on $\dot{V}O_2$ peak ($F_{(1, 23)} = 0.0, P > 0.05$). Similar results were observed for HRpeak, which was also higher for the GXT ($F_{(1, 23)} = 23.7, P < 0.001$). There was no significant difference in HRpeak between the able-bodied participants and paraplegic persons ($F_{(1, 23)} = 3.8, P = 0.065$) and no significant test x group interaction on HRpeak ($F_{(1, 23)} = 0.1, P > 0.05$). Further analysis showed that participants achieved a significantly higher POpeak during the ramp exercise test compared to the GXT ($F_{(1, 23)} = 110.1, P < 0.001$). It also showed that able-bodied participants achieved significantly higher POpeak during both exercise tests compared to paraplegic persons ($F_{(1, 23)} = 18.2, P < 0.05$) and there was no significant test x group interaction on POpeak ($F_{(1, 23)} = 0.9, P > 0.05$).

Participants reported similar overall RPEs ($F_{(1, 23)} = 1.8, P > 0.05$) and similar peripheral RPEs ($F_{(1, 23)} = 0.1, P > 0.05$) at the termination of the GXT and the ramp exercise test. There was also no significant difference between able-bodied and paraplegic persons in RPEo ($F_{(1, 23)} = 4.0, P = 0.058$) or in RPEp ($F_{(1, 23)} = 0.5, P > 0.05$). Finally, there was no significant test x group interaction on overall RPE ($F_{(1, 23)} = 0.3, P > 0.05$) or significant test x group interaction on peripheral RPE ($F_{(1, 23)} = 1.0, P > 0.05$).

However, paired sample t-tests showed that able-bodied participants reported a significantly higher peripheral RPE compared to overall RPE at the termination of the GXT ($t_{(12)} = 5.0, P < 0.001$) and the ramp exercise test ($t_{(12)} = 5.8, P < 0.001$). Similar analysis showed that paraplegic persons reported a significantly higher peripheral RPE compared to overall RPE at the termination of the GXT ($t_{(11)} = 4.2, P < 0.01$) and the ramp exercise test ($t_{(11)} = 5.6, P < 0.001$). As such, peripheral RPE was used to predict $\dot{V}O_2$ peak during the GXT and the ramp exercise test for able-bodied participants and paraplegic individuals.

Measured vs. predicted $\dot{V}O_2$ peak

Measured and predicted $\dot{V}O_2$ peak from the three RPE ranges (i.e., RPEs prior to and including RPE of 13, 15 and 17) for the GXT and the ramp exercise test for able-bodied participants and persons with paraplegia are presented in Table 6.2.

Table 6.2: $\dot{V}O_2$ peak ($ml \cdot kg^{-1} \cdot min^{-1}$) observed at the termination of the GXT and ramp exercise test and predicted $\dot{V}O_2$ peak from RPEs prior to and including RPE of 13, 15 and 17 for able-bodied and paraplegic individuals. These values are (mean \pm SD).

Exercise	Group	Measured	Predicted $\dot{V}O_2$ peak	Predicted $\dot{V}O_2$ peak	Predicted $\dot{V}O_2$ peak
		$\dot{V}O_2$ peak	from RPEs up to 13	from RPEs up to 15	from RPEs up to 17
GXT	Able-bodied	35 ± 7	$30 \pm 8^*$	$30 \pm 7^*$	$31 \pm 6^*$
	Paraplegic	31 ± 6	32 ± 10	31 ± 8	31 ± 6
Ramp	Able-bodied	33 ± 6	$29 \pm 5^*$	30 ± 5	32 ± 6
	Paraplegic	29 ± 5	$31. \pm 9$	$32 \pm 8^*$	31 ± 7

* Significant difference between measured and predicted $\dot{V}O_2$ peak $P < 0.05$. There was no test x group interaction ($F_{(1, 23)} = 0.0, P > 0.05$) and no test x method x group interaction ($F_{(1.7, 38,4)} = 0.1, P > 0.05$) on $\dot{V}O_2$ peak. However, there was a significant method x group interaction on $\dot{V}O_2$ peak ($F_{(3, 69)} = 7.1, P < 0.001$). The test x method interaction approached significance ($F_{(1.7, 38,4)} = 3.2, P = 0.06$). Post hoc analysis using Tukey's Honestly Significant Difference showed that predicted $\dot{V}O_2$ peak from RPEs prior to and including RPE13, 15 and 17 during the GXT and from RPEs up to and including RPE13 during the ramp exercise test were significantly lower than measured $\dot{V}O_2$ peak for able-bodied participants ($P < 0.05$). In addition, predicted $\dot{V}O_2$ peak from RPEs prior to and including RPE15 was significantly higher than measured $\dot{V}O_2$ peak during the ramp exercise test for paraplegic persons ($P < 0.05$).

Analysis of the consistency of the predictions in $\dot{V}O_2$ peak

Limits of agreement (LoA) and intraclass correlation coefficient (ICC) between measured and predicted $\dot{V}O_2$ peak from the three ranges of RPE (i.e., before and including RPE13, 15 and 17) when extrapolated to RPE20 are presented in Table 6.3. The assumption of homogeneity for the difference and the average between measured and predicted $\dot{V}O_2$ peak was met for all the RPE ranges except during the GXT for

paraplegic individuals for the RPE range before and including RPE13. That was because of a big difference between measured and predicted $\dot{V}O_2$ peak for one participant. As such, we did not convert the data to Log format but we reported LoA for this perceptual range with and without this participant.

Table 6.3: Limits of agreement and ICC between measured and predicted $\dot{V}O_2$ peak from RPEs up to and including RPE of 13, 15 and 17 extrapolated to RPE20 for able-bodied and paraplegic participants for the GXT and the ramp exercise test

Exercise	Group	RPEs up to 13	RPEs up to 15	from RPEs up to 17
GXT	Able-bodied LoA	-4 ± 12	-5 ± 8	-4 ± 7
	Able-bodied ICC	0.81	0.89	0.91
	Paraplegic LoA	-1 ± 11	0 ± 6	0 ± 4
	Paraplegic ICC	0.89	0.94	0.96
Ramp	Able-bodied LoA	-4 ± 8	-2 ± 8	-1 ± 6
	Able-bodied ICC	0.82	0.85	0.92
	Paraplegic LoA	-2 ± 14	3 ± 11	2 ± 7
	Paraplegic ICC	0.67	0.77	0.89

Comparison of % $\dot{V}O_2$ peak at RPE 13, 15 and 17 during the GXT and the ramp exercise test

There was no significant difference in proportions of $\dot{V}O_2$ peak observed at RPE13 between the GXT and the ramp exercise test ($F_{(1, 23)} = 1.2, P > 0.05$) and no significant test x group interaction on % $\dot{V}O_2$ peak ($F_{(1, 23)} = 0.7, P > 0.05$). However, paraplegic individuals achieved a significantly higher % $\dot{V}O_2$ peak at RPE13 ($F_{(1, 23)} = 28.2, P < 0.001$). Similar analysis revealed no significant difference in proportions of $\dot{V}O_2$ peak observed at RPE of 15 between the GXT and the ramp exercise test ($F_{(1, 23)} = 2.6, P > 0.05$) and no significant test x group interaction on % $\dot{V}O_2$ peak ($F_{(1, 23)} = 0.1, P > 0.05$). However, paraplegic persons achieved a significantly higher % $\dot{V}O_2$ peak at RPE of 15 ($F_{(1, 23)} = 17.2, P < 0.001$). Further analysis showed no significant difference in the proportions of $\dot{V}O_2$ peak observed at RPE of 17 between the GXT and the ramp exercise test ($F_{(1, 23)} = 3.0, P > 0.05$) and no significant test x group interaction on % $\dot{V}O_2$ peak ($F_{(1, 23)} = 0.2, P > 0.05$). However, paraplegic individuals achieved a

significantly higher % $\dot{V}O_2$ peak at RPE of 17 ($F_{(1, 23)} = 11.1, P < 0.01$). The mean (\pm SD) of % $\dot{V}O_2$ peak observed at peripheral RPE of 13, 15 and 17 during the GXT and the ramp exercise test for able-bodied and paraplegic individuals are presented in Table 6.4 and Figure 6.2.

Table 6.4: Proportions of $\dot{V}O_2$ peak at RPE13, 15 and 17 during the GXT and the ramp exercise test for able-bodied participants and persons with paraplegia. These values are (mean \pm SD).

Exercise	Group	% $\dot{V}O_2$ peak at	% $\dot{V}O_2$ peak at	% $\dot{V}O_2$ peak at
		RPE13	RPE15	RPE17
GXT	Able-bodied	52 \pm 5*	63 \pm 8*	77 \pm 8*
	Paraplegic	68 \pm 8	76 \pm 8	86 \pm 7
Ramp	Able-bodied	52 \pm 7*	68 \pm 11*	80 \pm 8*
	Paraplegic	65 \pm 11	79 \pm 9	88 \pm 6

* Significant difference between able-bodied and paraplegic persons $P < 0.01$

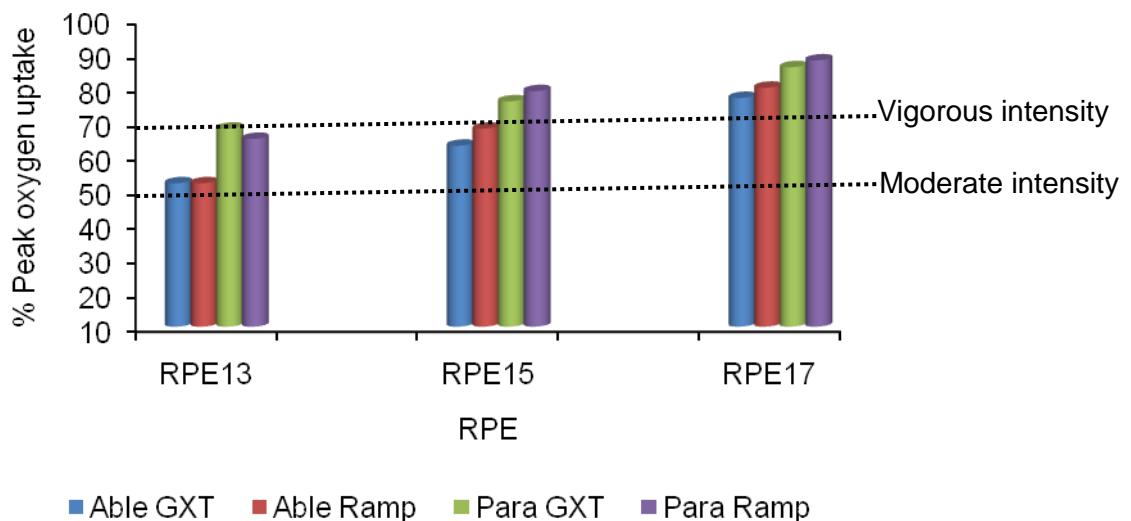


Figure 6.2: Proportions of $\dot{V}O_2$ peak observed at RPE13, 15 and 17 for able-bodied and paraplegic individuals during the GXT and the ramp exercise test

6.4 Discussion

This study was conducted to assess whether a GXT or a ramp exercise test could provide an acceptable prediction of $\dot{V}O_2$ peak using the RPE during arm cranking exercise in able-bodied participants and those with paraplegia. In accordance with previous studies (Demura and Nagasawa, 2003; Faulkner and Eston, 2007; Lambrick

et al., 2009; Skinner et al., 1973b), the current study showed a very strong linear relationship between peripheral RPE and $\dot{V}O_2$ during the GXT and the ramp exercise test for able-bodied participants ($R^2 \geq 0.95$ and $R^2 \geq 0.96$, respectively) and paraplegic individuals ($R^2 \geq 0.96$ and $R^2 \geq 0.95$, respectively).

GXT vs. ramp exercise test

Participants, irrespective of group, achieved significantly higher peak power output during the ramp exercise test compared to the GXT. However, time to exhaustion was significantly shorter during the ramp exercise test compared to the GXT for able-bodied (9.1 minutes and 13.4 minutes, respectively) and paraplegic persons (7.0 minutes and 9.7 minutes, respectively). This is in accordance with previous research during leg cycling (Boone et al., 2010). This has an important application during arm exercise as this may minimise the effect of localised fatigue on termination of the exercise test. Nevertheless, participants, irrespective of group, achieved significantly higher HRpeak and $\dot{V}O_2$ peak during the GXT compared to the ramp test. This is more likely attributed to the nature of the GXT which allows more time for the heart rate and $\dot{V}O_2$ to reach a steady-state at each stage compared to the ramp test (Eston et al., 2009).

Predicted vs. measured $\dot{V}O_2$ peak

Paraplegic individuals

For the paraplegic individuals, there was no significant difference between measured and predicted $\dot{V}O_2$ peak from the three RPE ranges (i.e., RPEs before and including RPE 13, 15 and 17) when extrapolated to RPE20 during the GXT. However, predicted $\dot{V}O_2$ peak from RPEs prior to and including RPE of 15 during the ramp exercise test was significantly higher than measured $\dot{V}O_2$ peak from the ramp exercise test. A more accurate prediction of $\dot{V}O_2$ peak was elicited from higher perceptual ranges (i.e., RPEs before and including RPE17) during the GXT and the ramp exercise test as reflected by narrower LoA and higher ICC. The GXT provided a more accurate prediction of $\dot{V}O_2$ peak compared to the ramp test as reflected by no significant

difference between measured and predicted $\dot{V}O_2$ peak from three RPE ranges, narrower LoA and higher ICC. If the one participant who caused a heteroscedastic error in the perceptual range up to and including RPE13 during the GXT is excluded, the LoA and ICC become 0 ± 7 and 0.83, respectively.

The more accurate prediction of $\dot{V}O_2$ peak during the GXT compared to the ramp exercise test might be attributed to the fact that more time was spent at each stage which makes it easier to estimate the feeling of exertion. This observation is not in accordance with the findings of Lambrick et al. (2009) who stated that a ramp exercise test provides a more accurate prediction of $\dot{V}O_2$ peak during leg cycling in healthy able-bodied participants as the continuous increase in the work rate may facilitate the appraisal of perceived exertion.

Able-bodied individuals

For able-bodied participants, prediction of $\dot{V}O_2$ peak from RPEs prior to and including RPE 13, 15 and 17 were significantly lower compared to measured $\dot{V}O_2$ peak during the GXT. In addition, prediction of $\dot{V}O_2$ peak from RPEs prior to and including RPE13 was significantly lower compared to measured $\dot{V}O_2$ peak during the ramp exercise test (Table 6.2). As expected, a more accurate prediction of $\dot{V}O_2$ peak was elicited from the higher perceptual ranges (i.e., RPEs before and including RPE 17) during both exercise tests as reflected by narrower LoA and higher ICC. However, the ramp exercise test provided a more accurate prediction of $\dot{V}O_2$ peak as reflected by no significant difference between measured and predicted $\dot{V}O_2$ peak from RPEs up to and including RPE15 and RPE17 and narrower LoA for the three RPE ranges compared to the GXT.

The lower predicted $\dot{V}O_2$ peak compared to the measured values in able-bodied participants might be attributed to two factors. Firstly, able-bodied participants may have overestimated their peripheral RPE at a given work rate which will have led to lower predicted $\dot{V}O_2$ peak compared to the measured value. Secondly, the higher

measured $\dot{V}O_2$ peak compared to the predicted value is most likely attributed to the contribution of the torso at high intensities during the maximal exercise tests. Future studies should use belts, similar to those used in cars, to minimise the contribution of the torso during maximal exercise tests as the current study utilised belts to stabilize and minimise the contribution of the lower limbs only.

Proportion of $\dot{V}O_2$ peak at peripheral RPE of 13, 15 and 17

Paraplegic individuals exercised at ~ 65 % $\dot{V}O_2$ peak at peripheral RPE of 13 during both exercise tests. This is in accordance with previous research during leg cycling (Parfitt et al., 1996; Faulkner and Eston, 2007; Lambrick et al., 2009), treadmill running (Eston et al., 1987) and arm cranking (chapter 4 (study 1)). This intensity is considered effective as it may elicit cardiorespiratory adaptations, ensure the safe application of an exercise test and improve the participants' adherence and sense of autonomy associated with exercise participation (Parfitt et al., 1996; ACSM, 2010). The able-bodied participants exercised at ~ 52 % $\dot{V}O_2$ peak at RPE of 13 which was significantly lower than that observed for paraplegic persons at the same RPE. This may be attributed to the able-bodied participants' relative lack of familiarity with arm exercise. The lower predicted $\dot{V}O_2$ peak from sub-maximal RPEs may also be attributed to this lack of familiarity. Nevertheless, the consistency of using the RPE to regulate exercise intensity during arm exercise in able-bodied and paraplegic individuals is evident in the study as each group exercised at similar proportions of $\dot{V}O_2$ peak during both exercise tests at RPEs of 13, 15 and 17 (Table 6.4).

Overall RPE vs. peripheral RPE

Participants reported significantly higher peripheral RPE (i.e., 19.6) compared to overall RPE (i.e., 18.2) at the termination of the GXT and the ramp exercise test. To our knowledge this is the first study which has looked into overall and peripheral RPE during peak arm crank exercise in individuals with paraplegia. These results are in agreement with the findings by Goosey-Tolfrey and Kirk, (2003) and Lenton et al. (2008) during wheelchair propulsion exercise. Lenton et al. (2008) observed higher

peripheral RPE compared to overall RPE and central RPE during wheelchair propulsion exercise in able-bodied and paraplegic individuals. The higher RPE_p compared to RPE_o is in accordance with previous research (Ekblom and Goldbarg, 1971; Demura and Nagasawa, 2003; Faulkner and Eston, 2007). This is most likely attributed to the smaller muscle mass activated during arm exercise (McArdle et al., 2007), which may in turn reflect the higher work rate per unit of contracting muscle mass (Åstrand et al., 2003). As such, it was more appropriate to use peripheral RPE, as RPE_o would eventually lead to an overestimation of $\dot{V}O_2$ peak.

6.5 Conclusion

For the paraplegic individuals, the GXT provided a more accurate prediction of $\dot{V}O_2$ peak as reflected by the narrower limits of agreement and higher intraclass correlation coefficients. However, for the able-bodied individuals, the ramp test was more accurate at predicting $\dot{V}O_2$ peak as reflected by no significant difference between measured and predicted $\dot{V}O_2$ peak from RPEs prior to and including RPE15 and RPE17 and narrower LoA for the three RPE ranges compared to the GXT. These observations have important implications in assessing peak functional capacity for paraplegic individuals in rehabilitation settings where maximal exercise testing is not feasible. In addition, the use of a sub-maximal exercise test will ensure a safer environment and may increase the participants' motivation to exercise by reducing the negative affect which might be associated with high exercise intensities.

The second and third studies assessed the utility of sub-maximal RPE values elicited during *estimation* procedures (ramp exercise test and graded exercise test vs. ramp exercise test, respectively) to predict peak oxygen uptake when these values were extrapolated to RPE20. Previous research has also indicated that $\dot{V}O_2$ peak may be predicted with reasonable accuracy from sub-maximal perceptually-guided, graded exercise test during leg cycling (Eston et al., 2005, 2006, 2008; Faulkner et al., 2007, 2007; Faulkner et al., 2009) and running on treadmill (Morris et al., 2009). Furthermore,

we have observed some differences between able-bodied and paraplegic individuals in the accuracy of predicting $\dot{V}O_2$ peak from sub-maximal RPE values elicited during *estimation* procedures. Therefore, the aim of the next study is to assess the accuracy of predicting $\dot{V}O_2$ peak from sub-maximal perceptually-guided, graded exercise test during arm cranking exercise in able-bodied and paraplegic individuals and whether participants' group (i.e., able-bodied and paraplegic) would moderate the findings.

Chapter seven

Study 4

The validity of predicting peak oxygen uptake from a perceptually-guided, graded exercise test in able-bodied and paraplegic individuals

Data from this chapter have contributed to:

Publication:

Harran Al-Rahamneh and Roger Eston (2010). The validity of predicting peak oxygen uptake from a perceptually-guided graded exercise test during arm exercise in paraplegic individuals. *Spinal Cord*, 1- 5.

Poster presentation:

Harran Al-Rahamneh and Roger Eston. Prediction of peak oxygen uptake from a perceptually-guided, graded exercise test during arm exercise in individuals with paraplegia. ECSS Conference 2010, Antalya, Turkey.

7.1 Introduction

Maximal oxygen uptake ($\dot{V}O_2\text{max}$) is considered by most physiologists as the best indicator of cardiovascular and respiratory fitness (Wilmore and Costill, 2004; ACSM, 2010). For reasons of cost and time, it is not always feasible to measure the $\dot{V}O_2\text{max}$. Therefore, based on the strong linear relationship between heart rate and $\dot{V}O_2$, sub-maximal heart rate values are usually used to predict $\dot{V}O_2\text{max}$ by extrapolating these values to age-predicted maximal heart rate (HRmax). However, individuals with high spinal cord injury (i.e., above the sixth thoracic vertebra (T6)) have an abnormal heart rate response due to their injury (Janssen and Hopman, 2005; Figoni, 2009). This may in turn affect the HRmax and consequently the ability to use age-predicted maximal heart rate to predict $\dot{V}O_2\text{max}$. In addition, arms elicit a lower peak heart rate compared to leg cycling and running on treadmill (Franklin et al., 1983; Vander et al., 1984; Borg et al., 1987; Aminoff et al., 1996) which will in turn lead to an overestimation of $\dot{V}O_2\text{max}$ when sub-maximal heart rate values are extrapolated to the age-predicted maximal heart rate.

The usual practice of Borg 6-20 Rating of Perceived Exertion Scale (RPE, Borg, 1998) is to ask the exerciser to rate how ‘hard’ the exercise feels during exercise. This procedure is frequently referred to as ‘*estimation*’, which is a *passive* process in which the RPE is free to vary. Conversely, the *production* procedure is an active process in which the RPE is prescribed and the individual produces an exercise intensity equating to a given RPE.

The RPE is a valid method of regulating exercise intensity using estimation-production procedures, whereby the exercise intensity is set according to a given RPE obtained from a previous exercise test in able-bodied and paraplegic individuals (Eston et al., 1987; Goosey-Tolfrey et al., 2010). Eston et al. (2005) showed that it is possible to apply the RPE production procedure in the form of a perceptually-guided, graded exercise test to estimate the $\dot{V}O_2\text{max}$ by extrapolation of sub-maximal $\dot{V}O_2$ values

elicited at overall RPEs of 9, 11, 13, 15 and 17 to RPE20 (i.e., maximal RPE) on the Borg 6-20 RPE scale.

The validity of the perceptually-guided exercise test to predict $\dot{V}O_2\text{max}$ has been assessed in healthy low-fit individuals (Eston et al., 2008), across various exercise durations at each RPE level (Eston et al., 2006), in low-fit and physically active individuals (Faulkner et al., 2007) and in continuous and discontinuous protocols (Eston et al., 2005, 2008; Morris et al., 2009; 2010). The prediction of $\dot{V}O_2\text{max}$ from sub-maximal, perceptually-guided exercise bouts has been shown to be valid and facilitates a safer and more widely applicable means of exercise testing by eliminating higher exercise intensities (RPE > 17) compared to the GXT. A further advantage of this procedure is that individuals are given the autonomy to control the intensity of the exercise, and this may be an important factor for exercise adherence.

Individuals with spinal cord injury or spinal cord disease are generally less physically active compared to their able-bodied counterparts (Owen and Jones, 1985; Collins et al., 2010). Depressive symptoms are often prevalent among these individuals (Bombardier et al., 2004), which in turn may lead to a lack of motivation to exercise (Birk, 2009). As such, use of a perceptually-guided exercise test to estimate peak oxygen uptake ($\dot{V}O_2\text{peak}$) is an alternative potential method.

Therefore, the aim of this study was to assess the accuracy of predicting $\dot{V}O_2\text{peak}$ from sub-maximal $\dot{V}O_2$ values elicited during a perceptually-guided, graded exercise test when extrapolated to RPE20 during arm cranking exercise. A further aim was to see whether the prediction of $\dot{V}O_2\text{peak}$ was moderated by the participants' group (i.e., able-bodied and paraplegic). We hypothesised that the perceptually-guided, graded exercise test would provide an acceptable estimation of $\dot{V}O_2\text{peak}$, regardless of group.

7.2 Methods

Participants

Twelve able-bodied men and 11 paraplegic men volunteered for the study (Table 7.1). Able-bodied participants were students from the School of Sport and Health Sciences at the University of Exeter, who were healthy, free from illnesses and pre-existing injuries and physically active (> 3 h per week) but not arm-trained (e.g., swimmer). With regard to paraplegic men, six of them had flaccid paralysis as a result of poliomyelitis infection and the other five had spinal cord injury (SCI) with neurological level at the sixth thoracic vertebra and below (i.e., T6 to L1), with years since injury ranging between 4 and 25 years. Paraplegic individuals were physically active (> 3 h per week) and participated in sports like wheelchair basketball, weightlifting and wheelchair racing. However, the form of arm crank ergometer used in this study was not a familiar mode of exercise training for both groups. Please see section (3.1 *Measurement of height and body mass (for all the studies)*) regarding how height and body mass were measured.

Data were collected with joint institutional ethics approval from the Faculty of Physical Education at the University of Jordan and the Ethics Committee of the School of Sport and Health Sciences at the University of Exeter. Able-bodied participants performed their exercise tests in the exercise physiology laboratory in the School of Sport and Health Sciences at the University of Exeter. Individuals with paraplegia performed their exercise tests in the exercise physiology laboratory at the Faculty of Physical Education at the University of Jordan.

Table 7.1: Demographic and relevant disability descriptions

Participants	Age (years)	Weight (kg)	Type of lesion	Lesion level	Years since injury
Para 1	34.0	69.0	Polio	-	-
Para 2	34.7	79.9	Polio	-	-
Para 3	34.8	60.0	Polio	-	-
Para 4	31.0	59.8	SCI	T6 incomplete	25.0
Para 5	33.0	58.2	Polio	-	-
Para 6	31.2	82.0	Polio	-	-
Para 7	41.2	53.5	Polio	-	-
Para 8	29.1	83.5	SCI	L1 complete	8.5
Para 9	29.9	49.4	SCI	T7 complete	19.5
Para 10	22.1	53.3	SCI	T11complete	4.1
Para 11	24.3	59.7	SCI	T6 incomplete	5.0
Mean ± SD	32.3 ± 4.7	64.4 ± 12.3	-	-	-
Able-bodied					
Mean ± SD	26.0 ± 4.0	76.7 ± 13.6	-	-	-

Procedures

Each participant (i.e., able-bodied and paraplegic) completed two sub-maximal, perceptually-guided exercise tests, separated by 48 hours, to predict $\dot{V}O_2$ peak. For more details about these exercise tests see section (3.7 *Perceptually-guided, graded exercise test*). In addition, each participant performed an arm cranking graded exercise test (GXT, started at 30 W and increased by 15 W every 2 minutes until volitional exhaustion), separated by 48-h from the second perceptually-guided exercise test, designed to establish $\dot{V}O_2$ peak (see section 3.6 *graded exercise test* for more details about the GXT). In accordance with Morris et al. (2009), the perceptually-guided, graded exercise tests preceded the GXT in order not to give the participants a complete familiarisation with the full RPE scale, particularly as sedentary and clinical populations may not experience this in real life situations. All participants were recommended to avoid moderate and vigorous exercise in the days prior to and between the exercise tests. All exercise tests were performed on exactly the same Lode arm ergometer equipment. Expired air was collected during the three exercise

tests. For more details about gas analysis and arm ergometry please see sections (3.3 *gas analysis and 3.4 arm ergometry*).

Measures

Borg 6-20 RPE Scale

Participants reported their overall and peripheral feelings of exertion at the end of each stage during the GXT and at the completion of the exercise and used the overall RPE to regulate the exercise intensity during the perceptually-guided exercise tests (Eston et al., 1987; Borg, 1998). For more details see section (3.2 *Borg 6-20 RPE Scale*).

Data analysis

A series of independent sample t-tests were used to compare the peak values observed at the termination of the GXT between able-bodied and paraplegic individuals. The mean $\dot{V}O_2$ values recorded during the last 20 s of the third minute at RPEs of 9, 11, 13, 15 and 17 during the perceptually-guided, graded exercise tests were regressed against the corresponding RPE in a linear regression analysis for each participant. Individual linear regression analyses using the sub-maximal $\dot{V}O_2$ values elicited in the RPE ranges RPE 9 - 13, 9 - 15 and 9 - 17 were then extrapolated to the theoretical maximal RPE (RPE20) on the Borg 6-20 RPE scale to predict $\dot{V}O_{2\text{peak}}$ (Figure 7.1). A series of two factor ANOVAs (Method; measured $\dot{V}O_{2\text{peak}}$ and predicted $\dot{V}O_{2\text{peak}}$ from RPE x Group; able-bodied and paraplegic) were used to compare measured $\dot{V}O_{2\text{peak}}$ versus predicted $\dot{V}O_{2\text{peak}}$ from the three RPE ranges (i.e., 9 - 13, 9 - 15 and 9 - 17) and whether participants' group moderated these findings. A three factor repeated-measure ANOVA (RPE; 9, 11, 13, 15 and 17 x Trial; production 1 and production 2 x Group; able-bodied and paraplegic) was used to compare proportions of $\dot{V}O_{2\text{peak}}$ observed at each RPE level and whether % $\dot{V}O_{2\text{peak}}$ was moderated by trial (i.e., production 1 and production 2) and/or group (i.e., able-bodied and paraplegic). A similar analysis was used to compare proportions of POpeak

observed at each RPE level and whether %POpeak was moderated by trial and/or group. The assumptions of sphericity for all tests were checked using Mauchly's test. Where sphericity assumptions were not confirmed, the Greenhouse-Geisser epsilon was used to correct the degrees of freedom (Field, 2009). Alpha was set at P 0.05 and adjusted accordingly Data were analysed using SPSS for Windows, PC software, version 16.

A Bland and Altman (1986) 95% LoA analysis was used to quantify the agreement (bias $\pm 1.96 \times$ SD difference) between measured and predicted $\dot{V}O_2$ peak for each RPE range for able-bodied and paraplegic individuals. In accordance with recommendations (Bland and Altman, 1986; Nevill and Atkinson, 1997), data were checked for heteroscedasticity by conducting a Pearson product-moment correlation analysis on the difference between the measured and predicted $\dot{V}O_2$ peak scores and the average of the two measurement scores, prior to LoA analysis. Intraclass correlation coefficients (ICC) were also calculated using a one-way random model to quantify the relationship between predicted $\dot{V}O_2$ peak and measured $\dot{V}O_2$ peak values.

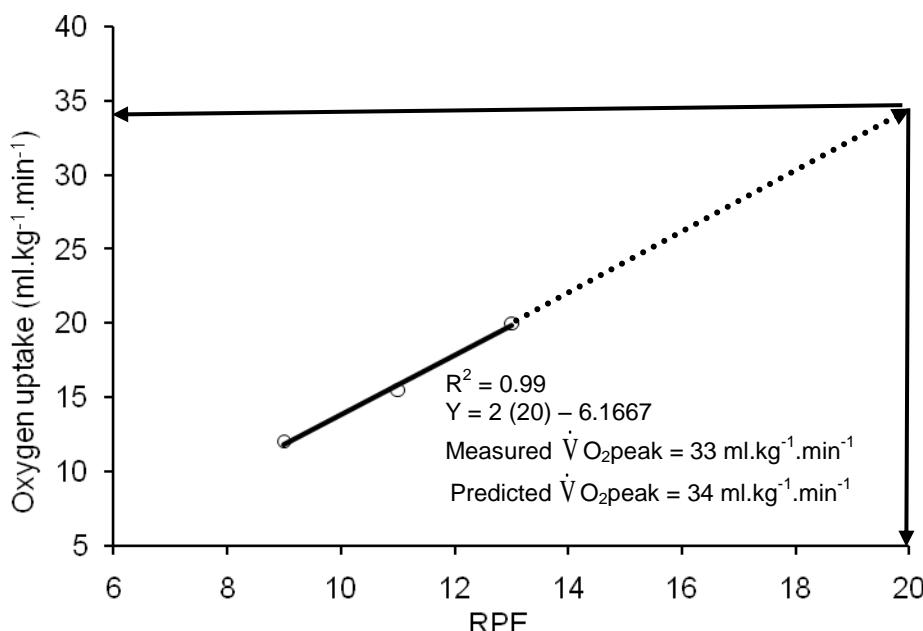


Figure 7.1: $\dot{V}O_2$ values elicited at RPEs of 9, 11 and 13 extrapolated to RPE20 on Borg 6-20 RPE Scale to predict $\dot{V}O_2$ peak for a paraplegic participant

7.3 Results

Descriptive statistics

All physiological, physical and perceptual values observed at the termination of the GXT for able-bodied and paraplegic individuals are presented in Table 7.2.

Table 7.2: Physiological, physical, overall RPE and peripheral RPE perceptual values observed at the termination of the GXT for able-bodied and paraplegic individuals. These are individual's values and mean \pm SD for groups.

Participants	PO (W)	HR (b.min ⁻¹)	$\dot{V}O_2$ (ml.kg ⁻¹ .min ⁻¹)	$\dot{V}O_2$ (L.min ⁻¹)	RER	RPEo	RPEp
Para 1	105	173	32	2.21	1.14	19	19
Para 2	105	159	27	2.16	1.29	20	20
Para 3	90	168	33	1.98	1.22	18	19
Para 4	90	187	31	1.85	1.22	19	19
Para 5	105	185	44	2.56	1.29	19	20
Para 6	120	148	30	2.46	1.14	20	20
Para 7	75	168	32	1.71	1.38	19	20
Para 8	105	170	26	2.17	1.28	17	19
Para 9	75	165	34	1.68	1.19	19	20
Para 10	60	178	24	1.28	1.34	19	19
Para 11	60	191	22	1.13	1.25	17	18
Mean \pm SD	90 ± 20	$172 \pm 13^*$	31 ± 6	1.94 ± 0.42	1.25 ± 0.08	18.7 ± 1.0	19.4 ± 0.7
Able-bodied							
Mean \pm SD	101 ± 18	156 ± 21	29 ± 6	2.18 ± 0.43	1.19 ± 0.06	18.1 ± 1.9	19.8 ± 0.5

* Significant difference between able-bodied and paraplegic individuals $P < 0.05$

Independent-sample t-tests revealed no significant difference between able-bodied and paraplegic individuals in POpeak ($t_{(21)} = 1.4$, $P > 0.05$), $\dot{V}O_2$ peak ($t_{(21)} = 0.6$, $P > 0.05$), RPEo ($t_{(16.9)} = 1.0$, $P > 0.05$) and RPEp ($t_{(21)} = 1.6$, $P > 0.05$). However, paraplegic individuals reached a significantly higher HRpeak ($t_{(21)} = 2.1$, $P < 0.05$) and higher RER values ($t_{(21)} = 2.0$, $P = 0.061$) compared to their paraplegic counterparts.

Measured vs. predicted $\dot{V}O_2$ peak

Measured and predicted $\dot{V}O_2$ peak for able-bodied and paraplegic individuals from the three RPE ranges (i.e., 9-13, 9-15 and 9-17) from the first and second perceptually-guided, graded exercise test are presented in Table 7.3.

Table 7.3: Measured and predicted $\dot{V}O_2$ peak for able-bodied and paraplegic individuals from the three RPE ranges (i.e. 9-13, 9-15 and 9-17) from the first (P1) and second (P2) perceptually-guided, graded exercise test. Values are (mean \pm SD).

Trial	Group	Measured	Predicted $\dot{V}O_2$ peak	Predicted $\dot{V}O_2$ peak	Predicted $\dot{V}O_2$ peak
		$\dot{V}O_2$ peak (ml.kg $^{-1}$.min $^{-1}$)	from RPEs 9-13 (ml.kg $^{-1}$.min $^{-1}$)	from RPEs 9-15 (ml.kg $^{-1}$.min $^{-1}$)	from RPEs 9-17 (ml.kg $^{-1}$.min $^{-1}$)
Production 1	Able-bodied	29 ± 6	$20 \pm 3^*$	$22 \pm 4^*$	$23 \pm 5^*$
	Paraplegic	31 ± 6	27 ± 5	30 ± 6	30 ± 6
Production 2	Able-bodied	29 ± 6	$22 \pm 4^*$	$22 \pm 4^*$	$23 \pm 4^*$
	Paraplegic	31 ± 6	30 ± 6	30 ± 6	31 ± 6

* Significant difference between measured and predicted $\dot{V}O_2$ peak from sub-maximal RPE when extrapolated to RPE20 $P < 0.05$

Two factor ANOVAs revealed a significant method \times group interaction on $\dot{V}O_2$ peak when it was predicted from RPEs 9-13 ($F_{(1, 21)} = 7.7, P < 0.05$), from RPEs 9-15 ($F_{(1, 21)} = 10.2, P < 0.05$) and from RPEs 9-17 ($F_{(1, 21)} = 11.9, P < 0.05$) during the first perceptually-guided, graded exercise test when sub-maximal $\dot{V}O_2$ and RPE values were extrapolated to RPE20. To follow up this interaction, Tukey's HSD revealed that predicted $\dot{V}O_2$ peak from the three RPE ranges (i.e., 9-13, 9-15 and 9-17) during the first perceptually-guided, graded exercise test were significantly lower than measured $\dot{V}O_2$ peak for able-bodied participants (all $P < 0.05$). A similar analysis revealed a significant method \times group interaction on $\dot{V}O_2$ peak when it was predicted from RPEs 9-13 ($F_{(1, 21)} = 16.1, P < 0.05$), from RPEs 9-15 ($F_{(1, 21)} = 16.2, P < 0.05$) and from RPEs 9-17 ($F_{(1, 21)} = 15.6, P < 0.05$) during the second perceptually-guided, graded exercise test when sub-maximal $\dot{V}O_2$ and RPE values were extrapolated to RPE20. Tukey's HSD revealed that predicted $\dot{V}O_2$ peak from the three RPE ranges (i.e., 9-13, 9-15 and

9-17) during the second perceptually-guided, graded exercise test were significantly lower than measured $\dot{V}O_2$ peak for able-bodied participants (all $P < 0.05$).

Proportions of $\dot{V}O_2$ peak observed at each RPE level during the first and second production trial

Proportions of $\dot{V}O_2$ peak observed at each RPE level during the first and second perceptually-guided, graded exercise test for able-bodied and paraplegic individuals are presented in Table 7.4 and Figure 7.2. Absolute oxygen uptake values observed at RPEs of 9, 11, 13, 15 and 17 during the first and the second production trials for able-bodied and paraplegic individuals are presented in Figures 7.3 and 7.4, respectively.

Table 7.4: Proportions of $\dot{V}O_2$ peak observed at each RPE level during the first and second production trials for able-bodied and paraplegic individuals. Values are (mean \pm SD).

Trial	Group	% $\dot{V}O_2$ peak				
		at RPE9	at RPE11	at RPE13	at RPE15	at RPE17
Production 1	Able-bodied	32 \pm 6	39 \pm 7*	46 \pm 8*	56 \pm 8*	70 \pm 9*
	Paraplegic	41 \pm 5°	50 \pm 6**	59 \pm 7**	71 \pm 8**	83 \pm 7**
Production 2	Able-bodied	31 \pm 6	39 \pm 8*	48 \pm 10*	58 \pm 10*	69 \pm 12*
	Paraplegic	41 \pm 7°	49 \pm 9*	62 \pm 7**	73 \pm 8**	84 \pm 7**

* Significant difference in % $\dot{V}O_2$ peak between the RPE levels (i.e., 9 and 13; 11 and 13; 13 and 15 and between 15 and 17) during the first and second production trials $P < 0.05$

° Significant difference between able-bodied and paraplegic individuals $P < 0.05$

A three factor ANOVA revealed a significant difference in % $\dot{V}O_2$ peak between the five RPE levels ($F_{(1.8, 37.8)} = 776.2$, $P < 0.001$) and that paraplegic individuals exercised at higher % $\dot{V}O_2$ peak compared to their able-bodied counterparts ($F_{(1, 21)} = 19.2$, $P < 0.001$). There was no significant difference between the first and second production trials in % $\dot{V}O_2$ peak ($F_{(1, 21)} = 1.1$, $P > 0.05$), although % $\dot{V}O_2$ peak tended to be higher (1% to 3%) during the second production trial compared to the first one. There was no significant trial x group interaction ($F_{(1, 21)} = 0.3$, $P > 0.05$), no significant RPE x trial interaction ($F_{(1.9, 40.3)} = 2.0$, $P > 0.05$) and no significant RPE x trial x group

on % $\dot{V}O_2$ peak ($F_{(4, 84)} = 0.6, P > 0.05$). However, there was a significant RPE x group interaction on % $\dot{V}O_2$ peak ($F_{(4, 37.8)} = 4.4, P < 0.01$).

To follow up the significant difference in % $\dot{V}O_2$ peak between the five RPE levels, paired sample t-tests, using Bonferroni adjustment, showed that participants, regardless of group, exercised at significantly higher % $\dot{V}O_2$ peak at RPE11 compared to RPE9 ($t_{(22)} = 17.5, P < 0.006$), at RPE13 compared to RPE11 ($t_{(22)} = 11.9, P < 0.006$), at RPE15 compared to RPE13 ($t_{(22)} = 18.0, P < 0.006$) and at RPE17 compared to RPE15 ($t_{(22)} = 16.7, P < 0.006$) during the first production trial. Similar findings were observed during the second production trial. To follow up the significant RPE x group interaction on % $\dot{V}O_2$ peak, independent-sample t-tests, using Bonferroni adjustment, revealed that paraplegic individuals exercised at significantly higher % $\dot{V}O_2$ peak during all the RPE levels during the first and the second production trials except at RPE11 during the second production trial ($t_{(21)} = 3.1, P > 0.005$).

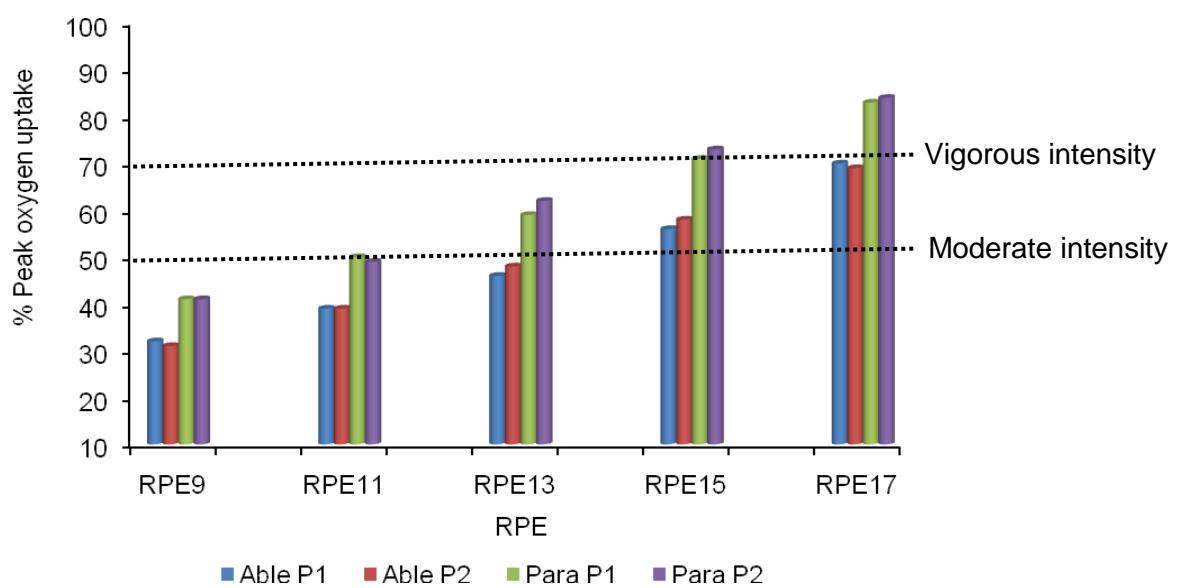


Figure 7.2: Proportions of % $\dot{V}O_2$ peak observed at RPE9, 11, 13, 15 and 17 for able-bodied and paraplegic individuals during the first (P1) and the second (P2) production trials

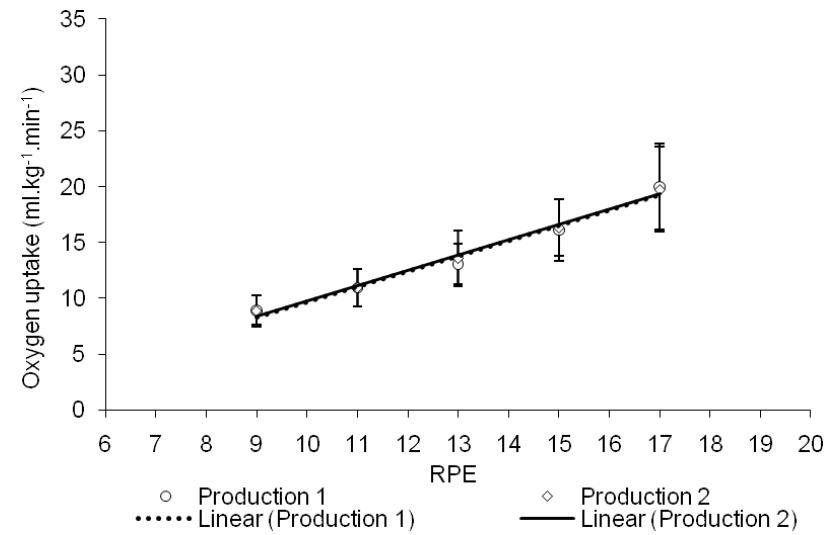


Figure 7.3: Absolute $\dot{V}O_2$ values observed at RPEs of 9, 11, 13, 15 and 17 during the first and the second production trials for able-bodied participants

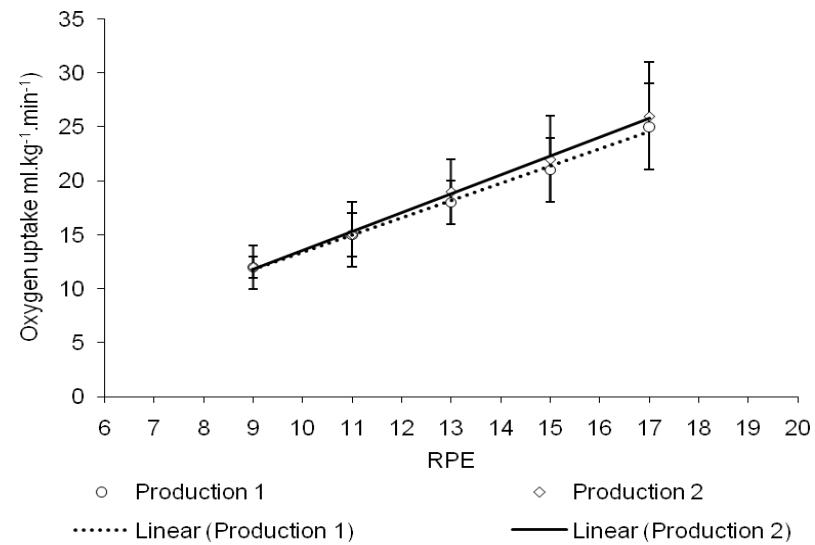


Figure 7.4: Absolute $\dot{V}O_2$ values observed at RPEs of 9, 11, 13, 15 and 17 during the first and the second production trials for paraplegic persons

Proportions of POpeak observed at each RPE during the first and second production

Proportions of POpeak observed at each RPE level during the first and second perceptually-guided, graded exercise test for able-bodied and paraplegic individuals are presented in Table 7.5.

Table 7.5: Proportions of POpeak observed at each RPE level during the first (P1) and second (P2) perceptually-guided, graded exercise test for able-bodied and paraplegic individuals. Values are (mean \pm SD).

Trial	Group	%POpeak	%POpeak	%POpeak	%POpeak	%POpeak
		at RPE9	at RPE11	at RPE13	at RPE15	at RPE17
Production 1	Able-bodied	13 \pm 4	23 \pm 6*	36 \pm 8*	51 \pm 9*	67 \pm 10*
	Paraplegic	14 \pm 4	28 \pm 5*	43 \pm 6*	59 \pm 7*	74 \pm 8*
Production 2	Able-bodied	13 \pm 4	23 \pm 5*	37 \pm 8*	51 \pm 9*	66 \pm 11*
	paraplegic	15 \pm 4	29 \pm 6*	46 \pm 8*	62 \pm 7*	77 \pm 10*

* Significant difference in %POpeak between the RPE levels (i.e., 9 and 13; 11 and 13; 13 and 15 and between 15 and 17) during the first and second production trials $P < 0.05$

A three factor ANOVA revealed a significant difference in %POpeak between the five RPE levels ($F_{(1.6, 33.2)} = 737.6$, $P < 0.001$) and that paraplegic individuals exercised at higher %POpeak compared to their able-bodied counterparts ($F_{(1, 21)} = 8.2$, $P < 0.01$). There was no significant difference between the first and second production trials in %POpeak ($F_{(1, 21)} = 2.8$, $P > 0.05$), although %POpeak tended to be higher (1% to 3%) during the second production trial compared to the first one for paraplegic individuals. There was no significant trial x group interaction ($F_{(1, 21)} = 2.2$, $P > 0.05$), no significant RPE x trial interaction ($F_{(1.7, 35.7)} = 0.4$, $P > 0.05$) and no significant RPE x trial x group on %POpeak ($F_{(4, 84)} = 0.6$, $P > 0.05$). However, there was a significant RPE x group interaction on % $\dot{V}O_2$ peak ($F_{(4, 84)} = 4.0$, $P < 0.01$).

To follow up the significant difference in %POpeak between the five RPE levels, paired sample t-tests, using Bonferroni adjustment, showed that participants, regardless of group, exercised at significantly higher %POpeak at RPE11 compared to RPE9 ($t_{(22)} = 17.1$, $P < 0.006$), at RPE13 compared to RPE11 ($t_{(22)} = 17.5$, $P < 0.006$),

at RPE15 compared to RPE13 ($t_{(22)} = 19.9, P < 0.006$) and at RPE17 compared to RPE15 ($t_{(22)} = 16.5, P < 0.006$) during the first production trial. Similar findings were observed during the second production trial. To follow up the significant RPE x group interaction on %POpeak, independent-sample t-tests, using Bonferroni adjustment, revealed no significant difference between able-bodied and paraplegic individuals in %POpeak at each RPE level during the first and the second production trials. However, paraplegic individuals exercised at higher %POpeak during all the RPE levels during the first and second production trials compared to their able-bodied counterparts. The differences were approaching significance at RPE13 ($P = 0.007$) and RPE15 ($P = 0.005$) during the second production trial.

Analysis of the consistency of the predictions in $\dot{V}O_2$ peak

Limits of agreement and intraclass correlation coefficient between measured and predicted $\dot{V}O_2$ peak from the three RPE ranges (i.e., 9-13, 9-15 and 9-17) during the first and second perceptually-guided, graded exercise tests for able-bodied and paraplegic individuals are presented in Table 7.6.

Table 7.6: LoA and ICC between measured and predicted $\dot{V}O_2$ peak ($ml.kg^{-1}.min^{-1}$) from the three RPE ranges (i.e., 9-13, 9-15 and 9-17) during the first and the second perceptually-guided, graded exercise tests for able-bodied and paraplegic individuals.

Trial	Group/LoA/ICC	RPEs 9 to 13	RPEs 9 to 15	RPEs 9 to 17
Production 1	Able-bodied LoA	-9 ± 10	-7 ± 8	-6 ± 7
	Able-bodied ICC	0.60	0.78	0.89
	Paraplegic LoA	3 ± 9	1 ± 10	1 ± 7
	Paraplegic ICC	0.75	0.75	0.89
Production 2	Able-bodied LoA	-7 ± 10	-7 ± 9	-6 ± 8
	Able-bodied ICC	0.66	0.73	0.81
	Paraplegic LoA	0 ± 6	0 ± 6	0 ± 6
	Paraplegic ICC	0.94	0.92	0.94

7.4 Discussion

This study showed very strong linear relationships between the RPE and $\dot{V}O_2$ values elicited from the GXT, the first and second production trials for both able-bodied and paraplegic individuals (all $R^2 \geq 0.96$, when re-converting the mean of Fisher Zr values to their corresponding R^2). This finding is in accordance with previous research, which used a perceptually-guided exercise test to predict $\dot{V}O_{2\max}$ in healthy, able-bodied individuals during leg cycling (Eston et al., 2005, 2006, 2008).

Able-bodied participants

There was a significant difference between measured $\dot{V}O_{2\text{peak}}$ and predicted $\dot{V}O_{2\text{peak}}$ from the three RPE ranges (i.e., RPEs 9 - 13, 9 - 15 and 9 - 17) when extrapolated to RPE20 during the first and second production trials. These significantly lower predicted $\dot{V}O_{2\text{peak}}$ values are not surprising as able-bodied individuals are not as familiar with arm exercise compared to paraplegic individuals. The significantly lower % $\dot{V}O_{2\text{peak}}$ at each RPE level for able-bodied participants compared with those with paraplegic confirms their less familiarity with arm exercise. Although they were physically active, none of them were arm-trained (e.g., swimmer or kayaker). In accordance with previous research (Eston et al., 2005, 2006, 2008; Faulkner et al., 2007), the higher RPE range (i.e., 9 -17) provided a more accurate prediction of $\dot{V}O_{2\text{peak}}$ as reflected by closer mean values, higher ICC and narrower LoA between measured and predicted $\dot{V}O_{2\text{peak}}$ values compared to the lower RPE ranges (i.e., 9 - 13 and 9 – 15).

Paraplegic individuals

There were no significant differences between measured and predicted $\dot{V}O_{2\text{peak}}$ values from the three RPE ranges (i.e., RPEs 9 - 13, 9 - 15 and 9 - 17) when extrapolated to RPE20 from the two perceptually-guided exercise tests. These findings are in agreement with previous research (Eston et al., 2005, 2006). The high RPE range (i.e., RPE 9-17) may be excluded from the second perceptually-guided test

without loss of accuracy in predicting of $\dot{V}O_2$ peak. This is an important application for sedentary individuals and for clinical populations (Coquart et al., 2010; Morris et al., 2010), although these observations are not in agreement with previous observations. Eston et al. (2008) observed lower predicted $\dot{V}O_2$ max values from three production trials when an RPE of 17 was excluded.

It should be borne in mind that all the participants in the present study were physically active with some competing at national level (e.g., one participant was a national wheelchair racer). It is possible that the participants' familiarity with regular exercise in this study may affect their ability to perceptually regulate specific intensities according to a given, prescribed RPE. In this regard, Faulkner et al. (2007), observed that able-bodied, physically active individuals showed less variability in reproducing a given exercise intensity at prescribed RPEs across several trials.

Nevertheless, it should be noted that despite the non-significant differences between predicted and actual $\dot{V}O_2$ peak from the three RPE ranges, LoA and ICC analysis indicated that the prediction of $\dot{V}O_2$ peak was more accurate when estimated from the higher perceptual ranges (i.e., RPEs 9-17) during the first perceptually-guided test (Table 7.6). The second perceptually-guided test also provided a more accurate prediction of $\dot{V}O_2$ peak as reflected by the closer measured and predicted $\dot{V}O_2$ peak values, narrower LoA and higher ICC (Tables 7.3 and 7.6).

Paraplegic participants exercised at a higher %POpeak and a significantly higher % $\dot{V}O_2$ peak at RPEs of 9, 11, 13, 15 and 17 compared to their able-bodied counterparts. This may in turn reflect that paraplegic individuals are more familiar with arm exercise compared to able-bodied individuals. This was also reflected in the more accurate prediction of $\dot{V}O_2$ peak from the three RPE ranges for paraplegic individuals compared to their able-bodied counterparts. In other words, paraplegic individuals are more accurate in gauging the exercise intensity using the RPE.

This study shows the importance of using LoA to assess the agreement between the two methods of measuring the $\dot{V}O_2$ peak. For instance, it seems from using the means and standard deviations alone, that the prediction of $\dot{V}O_2$ peak is very accurate, especially when estimated from the second production trial. However, when LoA was used to assess the accuracy of predicted $\dot{V}O_2$ peak against the measured value, there was a margin error of $\pm 6 \text{ ml.kg}^{-1}.\text{min}^{-1}$ (20%) between measured and predicted $\dot{V}O_2$ peak for the three ranges of RPE.

7.5 Conclusion

This study has shown a very strong linear relationship between the RPE and $\dot{V}O_2$ during perceptually-guided exercise tests, regardless of group. For paraplegic persons, the results provide encouraging evidence that $\dot{V}O_2$ peak may be estimated with reasonable accuracy from sub-maximal $\dot{V}O_2$ values elicited during a perceptually-guided exercise test especially after a full familiarization trial. They also imply that the higher RPE range (i.e., RPEs 9 - 17) can be eliminated with little loss of the accuracy in the prediction of $\dot{V}O_2$ peak. However, predicted $\dot{V}O_2$ peak values from the three RPE ranges were significantly lower compared to measured $\dot{V}O_2$ peak for able-bodied participants.

In this study, we observed a significantly lower prediction of $\dot{V}O_2$ peak from a perceptually-guided, graded exercise test during arm cranking exercise in able-bodied participants. Therefore, the aim of the next two studies is, firstly, to assess the accuracy of predicting $\dot{V}O_2$ peak from POpeak using the equation introduced by the ACSM (ACSM, 2006). Secondly, to assess the accuracy of predicting POpeak from the same perceptually-guided, graded exercise test in another group of able-bodied individuals.

Chapter eight

Study 5a

**The validity of estimating peak oxygen uptake from peak power output during
arm cranking exercise in able-bodied and paraplegic individuals using the ACSM
equation**

&

Study 5b

**The validity of predicting peak power output from a perceptually-guided, graded
exercise test during arm cranking exercise in able-bodied participants**

8.1 Introduction

Arm exercise is a justified mode of exercise testing and prescription for people who use their upper body regularly during exercise, such as rowers, swimmers and kayakers (Franklin, 1985). Similarly, for those who do some kind of work which requires using the upper body such as digging and snow shovelling. Furthermore, it is an appropriate mode of exercise testing and prescription for specific populations who are unable to use their legs during exercise. For instance, individuals with paraplegia as a result of spinal cord injury or spinal cord disease as well as for those with bilateral above-knee amputees (Hopman, 1994).

It is well established that arm exercise elicits lower peak values for oxygen uptake ($\dot{V}O_2$), ventilation (\dot{V}_E), heart rate and power output (PO) compared to leg cycling (Franklin et al., 1983; Vander et al., 1984; Borg et al., 1987; Aminoff et al., 1996). However, at a given sub-maximal work rate arms elicit higher values for oxygen uptake, \dot{V}_E , ventilatory equivalent for oxygen uptake ($\dot{V}_E/\dot{V}O_2$), heart rate, rating of perceived exertion and blood lactate levels compared to leg cycling (Franklin et al., 1983; Vander et al., 1984; Eston and Brodie, 1986; Borg et al., 1987).

Previous research has indicated that maximal functional capacity ($\dot{V}O_{2\max}$) may be predicted with reasonable accuracy from a sub-maximal perceptually-guided, graded exercise test in able-bodied individuals during leg cycling (Eston et al., 2005, 2006; Faulkner et al., 2007, 2009; Lambrick et al., 2009) and running on a treadmill (Morris et al., 2009, 2010). In addition, the accuracy of predicting peak functional capacity ($\dot{V}O_{2\text{peak}}$) from a sub-maximal perceptually-guided, graded exercise test may be a viable and preferred alternative method, as was shown in study 4. However, in the previous study (study 4) a lower estimation of $\dot{V}O_{2\text{peak}}$ was observed in the able-bodied participants compared to their paraplegic counterparts.

As indicated previously, $\dot{V}O_{2\text{peak}}$ is a valuable indicator of cardiorespiratory fitness (Wilmore and Costill, 2004; ACSM, 2010). It has also been indicated that

$\dot{V}O_2$ peak is a strong predictor of death in patients with heart disease as well as in all-cause of death (Vanhees et al., 1994; Kavanagh et al., 2002). However, measuring $\dot{V}O_2$ peak is expensive and it needs to be conducted in laboratory setting which is not always possible. In addition, it is not feasible to measure peak oxygen uptake for large groups of people. For the above reasons, some equations have been prescribed to estimate $\dot{V}O_2$ peak during cycling, walking and running on treadmill and during arm cranking exercise.

Therefore, the first aim of this chapter was to assess the validity of estimating $\dot{V}O_2$ peak from peak power output (POpeak) during arm cranking exercise using the equation described by the ACSM (i.e., $\dot{V}O_2 \text{ ml.kg}^{-1}.\text{min}^{-1} = 3 \times \text{work rate (kg.m.min}^{-1})/\text{body mass (kg)} + 3.5 \text{ ml.kg}^{-1}.\text{min}^{-1}$, ACSM, 2006) and whether the findings were moderated by group (study 5a). We hypothesised that the ACSM equation will provide accurate estimation of $\dot{V}O_2$ peak from POpeak, regardless of group. The second aim of this chapter was to assess the accuracy of predicting POpeak from a sub-maximal perceptually-guided, graded exercise test in another independent group of able-bodied participants (study 5b). In other words, we wished to assess the repeatability of the findings we observed in study 4. We hypothesised that the perceptually-guided, graded exercise test will not provide accurate prediction of POpeak for able-bodied participants when sub-maximal RPE and PO values were extrapolated to RPE20.

8.2 Methods

Study 5a

Participants

Fourteen able-bodied men and 14 paraplegic men (Table 8.1) volunteered to take part in the study. Able-bodied participants were sport science students studying at the University of Exeter. The able-bodied participants were healthy, free from illnesses and pre-existing injuries and physically active (> 3 h per week) but not arm-trained

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(e.g., swimmer). With regard to the paraplegic individuals, eight of them had flaccid paralysis of the lower limbs as a result of poliomyelitis infection. The other six had spinal cord injury (SCI) with neurological level at the sixth thoracic vertebra and below (i.e., T6 to the first lumbar vertebra (L1)). The duration since injury ranged between 4.1 and 25 years (please see Table 8.1 for more details about relative disability description). The paraplegic participants were physically active (> 3 h per week) and participated in such sports as wheelchair basketball, table tennis, weightlifting and wheelchair racing at both professional and recreational levels. However, the specific mode of arm ergometry used in this study was not a familiar mode of exercise training for both groups.

Table 8.1: Participant characteristics and relative disability description

Participant	Age (years)	Height (cm)	Body mass (kg)	Type of injury	Years since onset of SCI	Lesion level
Para 1	34.0	160	69.1	Polio	-	-
Para 2	34.7	160	79.9	Polio	-	-
Para 3	34.8	170	60.0	Polio	-	-
Para 4	31.0	165	59.8	SCI	25.0	T6 incomplete
Para 5	33.0	173	58.2	Polio	-	-
Para 6	31.2	178	82.0	Polio	-	-
Para 7	41.2	169	53.5	Polio	-	-
Para 8	29.1	180	83.5	SCI	8.5	L1 complete
Para 9	29.9	170	49.4	SCI	19.5	T7 complete
Para 10	22.1	167	53.3	SCI	4.1	T11 complete
Para 11	34.3	170	59.7	SCI	4.8	T6 incomplete
Para 12	38.3	160	66.0	Polio	-	-
Para 13	33.4	173	75.0	Polio	-	-
Para 14	19.9	171	60.0	SCI	7.0	T10 complete
Mean ± SD	31.9 ± 5.6	169.0 ± 6.2	65.0 ± 11.2	-	-	-
Able-bodied						
Mean ± SD	26.1 ± 4.0	175.9 ± 8.0	77.5 ± 12.8	-	-	-

Procedures

Each participant (i.e., able-bodied and paraplegic) completed an arm cranking graded exercise test (GXT, started at 30 W and increased by 15 W every 2 minutes until volitional exhaustion), designed to establish $\dot{V}O_2$ peak. For more details about the GXT please see section (*3.6 graded exercise test*). All participants were recommended to avoid moderate and vigorous exercise in the day prior to the exercise test. All exercise tests were performed on the same Lode arm ergometry. Expired air was analysed during this exercise test. For more details about gas analysis and the arm ergometry please sections (*3.3 gas analysis and 3.4 arm ergometry*). Participants were asked to report their overall RPE and peripheral RPE at the end of each stage as well as at the termination of the GXT. For more details about the RPE scale see section (*3.2 Borg 6-20 RPE Scale and Table 2.1*).

Data analysis

A series of independent sample t-tests were used to compare the peak values (i.e., $\dot{V}O_2$ peak, HRpeak, RER and POpeak) observed at the termination of the GXT between able-bodied and paraplegic individuals. In addition, a two factor ANOVA (Method; measured $\dot{V}O_2$ peak and estimated $\dot{V}O_2$ peak from POpeak using the ACSM equation x Group; able-bodied and paraplegic) was conducted to compare measured $\dot{V}O_2$ peak versus estimated $\dot{V}O_2$ peak from POpeak using the ACSM equation (ACSM, 2006) and between groups. Data were analysed using SPSS for Windows, PC software, version 16.

Limits of agreement analysis (LoA, Bland and Altman, 1986) was also used to assess the agreement between measured $\dot{V}O_2$ peak and estimated $\dot{V}O_2$ peak from the ACSM equation. In accordance with recommendations (Bland and Altman, 1986), data were checked for heteroscedasticity by conducting a Pearson product-moment correlation analysis on the difference between the measured and predicted $\dot{V}O_2$ peak

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scores and the average of the two measurement scores, prior to LoA analysis. Intraclass correlation coefficients (ICC) were also calculated using a one-way random model to quantify the relationship between predicted $\dot{V}O_2$ peak and measured $\dot{V}O_2$ peak values.

Study 5b

Participants

Fourteen able-bodied men (mean \pm SD, 24.9 \pm 3.6 y; 176.8 \pm 7.2 cm; 78.9 \pm 10.6 kg) volunteered for the study. All participants were students from the School of Sport and Health Sciences at the University of Exeter, who were healthy, free from illnesses and pre-existing injuries and physically active (> 3 h per week) but not arm-trained (e.g., swimmer). Please see section (3.1 *Measurement of height and body mass*) for more details regarding how height and body mass were measured.

Procedures

Each participant completed two sub-maximal, perceptually-guided exercise tests, separated by 48 hours, to predict peak power output (see section (3.7 *Perceptually-guided, graded exercise test*) for more details about these exercise tests). In addition, each participant performed an arm cranking graded exercise test (GXT, started at 30 W and increased by 15 W every 2 minutes until volitional exhaustion), separated by 48 hours from the second perceptually-guided exercise test, designed to establish POpeak (see section (3.6 *graded exercise test*) for more details about the GXT). In accordance with Morris et al. (2009), the perceptually-guided, graded exercise tests preceded the GXT in order not to give the participants a complete familiarisation with the full RPE scale, particularly as sedentary and clinical populations may not experience this in real life situations. All participants were recommended to avoid moderate and vigorous exercise in the days prior to and between the exercise tests. Heart rate was recorded during the last 20 s of each stage and at the completion of the

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exercise test using a wireless chest strap telemetry system (Polar Electro T31, Kempele, Finland). For arm ergometry used please see section (3.4 arm ergometry). Participants were asked to report their overall RPE at the end of each stage as well as at the termination of the GXT. Please see section (3.2 Borg 6-20 RPE Scale) for more details about the RPE scale and Table 2.1. Expired air was not collected during this study.

Data analysis

The mean power output values recorded during the last 20 s of the third minute at RPEs of 9, 11, 13, 15 and 17 during the perceptually-guided, graded exercise tests were regressed against the corresponding RPE in a linear regression analysis for each participant. Individual linear regression analyses using the sub-maximal power output values elicited in the RPE ranges RPE 9 - 13, 9 - 15 and 9 - 17 were then extrapolated to RPE20 on the Borg 6-20 RPE scale to predict POpeak. A series of paired sample t-tests were used to compare predicted and measured POpeak from the three RPE ranges (i.e., 9 - 13, 9 - 15 and 9 - 17). Data were analysed using SPSS for Windows, PC software, version 16.

Limits of agreement analysis were used to quantify the agreement (bias \pm 1.96 \times SD difference) between measured and predicted POpeak for each RPE range. In accordance with recommendations, data were checked for heteroscedasticity by conducting a Pearson product-moment correlation analysis on the difference between the measured and predicted POpeak scores and the average of the two measurement scores, prior to LoA analysis. Intraclass correlation coefficients (ICC) were also calculated using a one-way random model to quantify the relationship between predicted POpeak and measured POpeak values.

8.3 Results

Study 5a

Descriptive statistics

All physiological, physical and perceptual values observed at the termination of the GXT for able-bodied and paraplegic individuals are presented in Table 8.2.

Table 8.2: Peak physiological, physical and perceptual values observed at the termination of the GXT for able-bodied and paraplegic individuals. These are individual's values and mean \pm SD for groups.

Participant	PO (W)	HR (b.min ⁻¹)	̇V _{O₂} (ml.kg ⁻¹ .min ⁻¹)	̇V _{O₂} (L.min ⁻¹)	RER	RPEo	RPEp
Para 1	105	173	32	2.21	1.14	19	19
Para 2	105	159	27	2.16	1.29	20	20
Para 3	90	168	33	1.98	1.22	18	19
Para 4	90	187	31	1.85	1.22	19	19
Para 5	105	185	44	2.56	1.29	19	20
Para 6	120	148	30	2.46	1.14	20	20
Para 7	75	168	32	1.71	1.38	19	20
Para 8	105	170	26	2.17	1.28	17	19
Para 9	75	165	34	1.68	1.19	19	20
Para 10	60	178	24	1.28	1.34	19	19
Para 11	60	191	22	1.13	1.25	17	18
Para 12	120	180	35	2.31	1.21	17	17
Para 13	90	186	29	2.18	1.28	19	20
Para 14	105	207	34	2.04	1.17	19	20
Mean \pm SD	93 ± 20	$176 \pm 15^*$	31 ± 5	1.99 ± 0.39	$1.24 \pm 0.07^*$	18.6 ± 1.0	19.3 ± 0.9
Able-bodied							
Mean \pm SD	104 ± 19	158 ± 20	29 ± 6	2.25 ± 0.44	1.18 ± 0.08	18.0 ± 1.8	19.8 ± 0.4

* Significant difference between able-bodied and paraplegic individuals $P < 0.05$

Measured ̇V O₂peak and predicted ̇V O₂peak from the ACSM equation

Measured ̇V O₂peak and predicted ̇V O₂peak from PO_{peak} using the ACSM equation (i.e., ̇V O₂ (ml.kg⁻¹.min⁻¹) = 3 x work rate (kg.m.min⁻¹)/body mass (kg) + 3.5 (ml.kg⁻¹.min⁻¹)) for able-bodied and paraplegic individuals are presented in Table 8.3.

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Table 8.3: Measured $\dot{V}O_2$ peak and predicted $\dot{V}O_2$ peak from PO_{peak} using the ACSM equation for able-bodied and paraplegic individuals. Values are (mean \pm SD).

Group	Measured $\dot{V}O_2$ peak (ml.kg ⁻¹ .min ⁻¹)	Predicted $\dot{V}O_2$ peak from PO _{peak} (ml.kg ⁻¹ .min ⁻¹)
Able-bodied	29 \pm 6	29 \pm 5
Paraplegic	31 \pm 5	30 \pm 5

A two factor ANOVA showed no significant difference between measured $\dot{V}O_2$ peak and predicted $\dot{V}O_2$ peak from PO_{peak} using the ACSM equation ($F_{(1, 26)} = 3.4$, $P > 0.05$). There was also no significant difference between able-bodied and paraplegic individuals in $\dot{V}O_2$ peak ($F_{(1, 26)} = 0.6$, $P > 0.05$) and no significant method x group interaction on $\dot{V}O_2$ peak ($F_{(1, 26)} = 0.0$, $P > 0.05$).

Consistency of $\dot{V}O_2$ peak predictions

A limits of agreement and intraclass correlation coefficient analysis between measured and predicted $\dot{V}O_2$ peak from the ACSM equations are presented in Table 8.4. Limits of agreement between measured and predicted $\dot{V}O_2$ peak for able-bodied and paraplegic individuals are presented in Figures 8.1 and 8.2, respectively.

Table 8.4: LoA and ICC between measured and predicted $\dot{V}O_2$ peak from the ACSM equation

Group	LoA between measured and predicted $\dot{V}O_2$ peak (ml.kg ⁻¹ .min ⁻¹)	ICC between measured and predicted $\dot{V}O_2$ peak (ml.kg ⁻¹ .min ⁻¹)
Able-bodied	1 \pm 5	0.94
Paraplegic	1 \pm 5	0.94

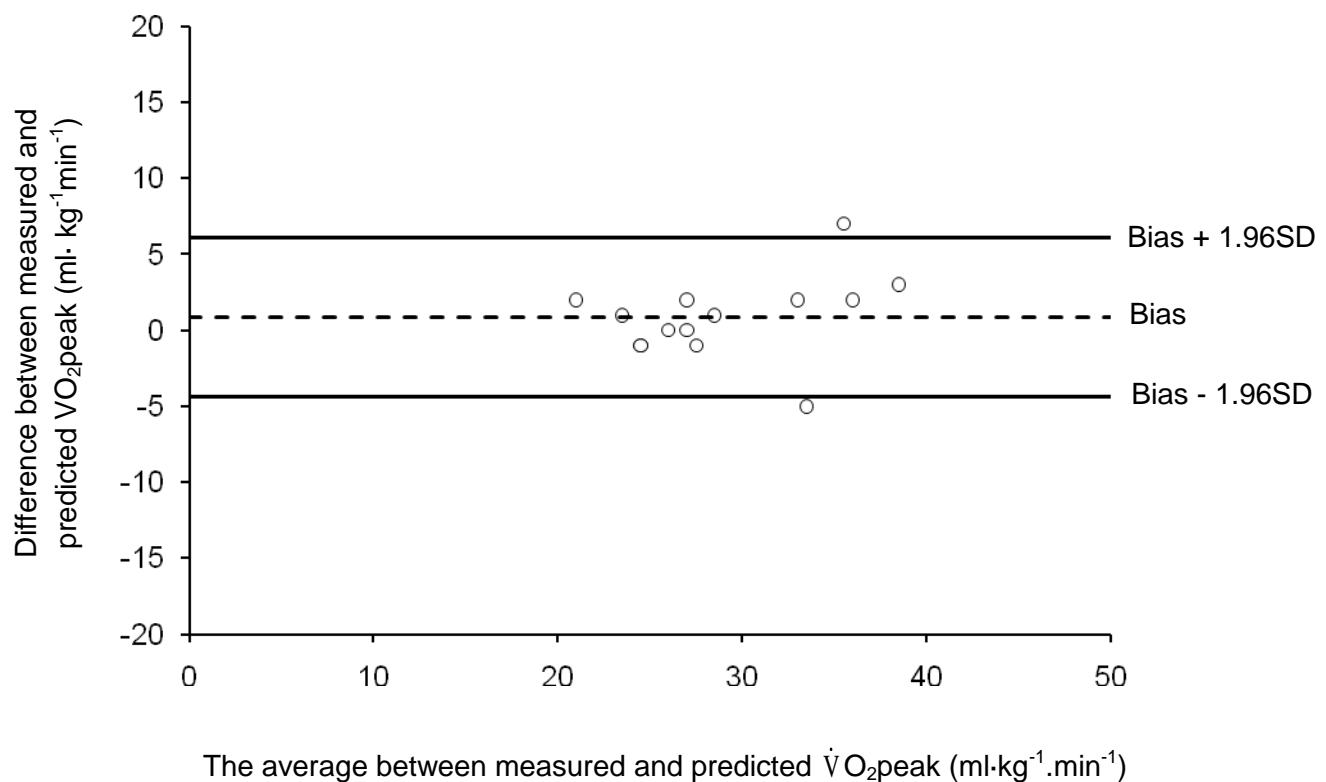


Figure 8.1: The 95% limits of agreement (bias $\pm 1.96 \times SD$ difference, $ml \cdot kg^{-1} \cdot min^{-1}$) for measured $\dot{V}O_2$ peak and predicted $\dot{V}O_2$ peak from the ACSM equation for able-bodied participants

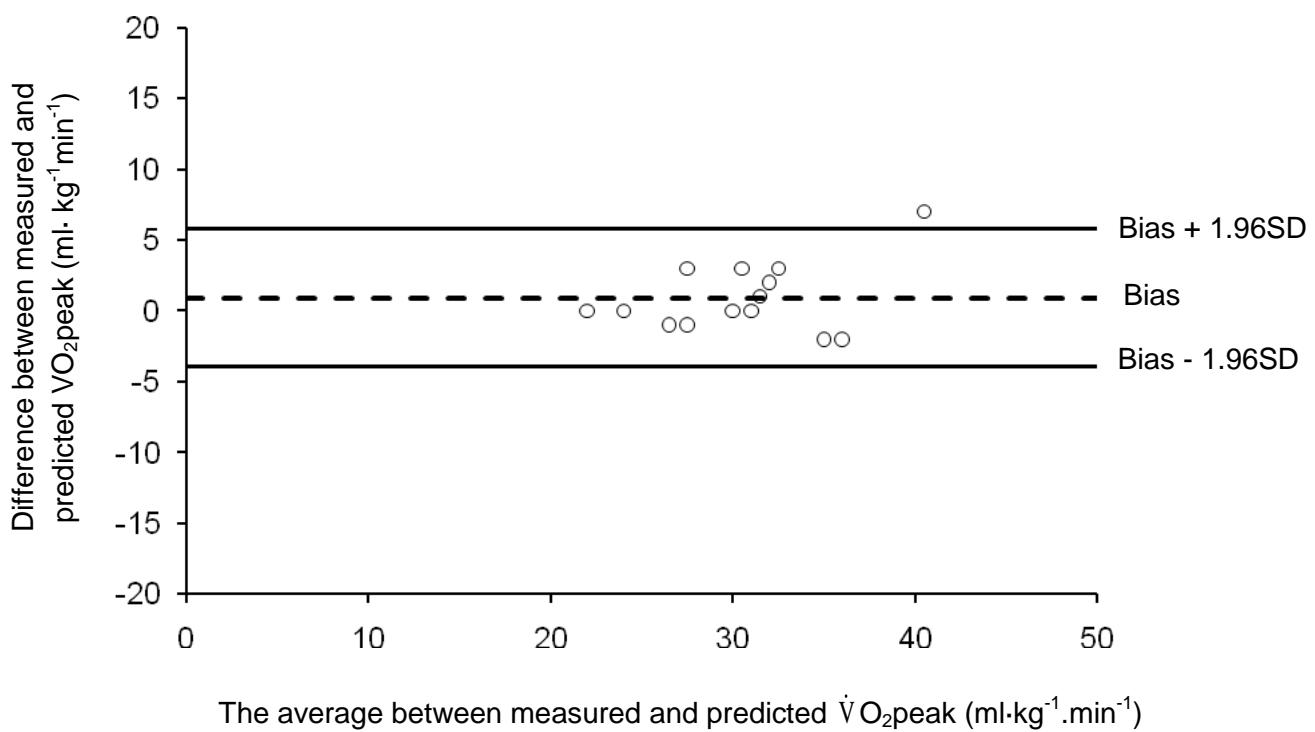


Figure 8.2: The 95% limits of agreement (bias $\pm 1.96 \times SD$ difference, $ml \cdot kg^{-1} \cdot min^{-1}$) for measured $\dot{V}O_2$ peak and predicted $\dot{V}O_2$ peak from the ACSM equation for paraplegic individuals

Study 5b

Descriptive statistics

Physical and perceptual values observed at the termination of the GXT are presented in Table 8.5.

Table 8.5: Physical and perceptual values observed at the termination of the GXT. Values are (mean \pm SD).

PO (W)	HR (b.min $^{-1}$)	$\dot{V}O_2$ (ml.kg $^{-1}$.min $^{-1}$)	Overall RPE
120 \pm 12	166 \pm 11	32 \pm 4*	19.6 \pm 0.6

* Predicted from peak power output

Measured POpeak vs. predicted POpeak

Measured and predicted POpeak for able-bodied individuals from the three RPE ranges (i.e., 9-13, 9-15 and 9-17) during the first and the second perceptually-guided, graded exercise test are presented in Table 8.6.

Table 8.6: Measured and predicted POpeak from the three RPE ranges (i.e., 9-13, 9-15 and 9-17) during the first (P1) and the second (P2) perceptually-guided, graded exercise test. Values are (mean \pm SD).

Trial	Measured POpeak (W)	Predicted POpeak	Predicted POpeak	Predicted POpeak
		from RPEs 9-13 (W)	from RPEs 9-15 (W)	from RPEs 9-17 (W)
Production 1	120 \pm 12	101 \pm 12*	106 \pm 11*	110 \pm 11*
Production 2	120 \pm 12	107 \pm 13*	111 \pm 13*	115 \pm 11

* Significant difference between measured and predicted POpeak $P < 0.05$

Paired sample t-tests showed that predicted peak power output was significantly lower from RPEs 9-13 ($t_{(13)} = 5.13, P < 0.05$), 9-15 ($t_{(13)} = 4.73, P < 0.05$) and 9-17 ($t_{(13)} = 4.0, P < 0.05$) when extrapolated to RPE20 during the first perceptually-guided, graded exercise test compared to measured POpeak. A similar analysis revealed that predicted POpeak was significantly lower from RPEs 9-13 ($t_{(13)} = 3.27, P < 0.05$) and 9-15 ($t_{(13)} = 2.27, P < 0.05$) compared to measured POpeak during the second perceptually-guided, graded exercise test when extrapolated to

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RPE20. However, no significant difference was observed between measured and predicted POpeak from RPEs 9-17 ($t_{(13)} = 1.57$, $P > 0.05$) during the second production trial.

The predicted peak oxygen uptake values for measured POpeak and predicted POpeak using the ACSM equation are presented in Table 8.7.

Table 8.7: The predicted $\dot{V}O_2$ peak for measured POpeak and predicted POpeak from the three sub-maximal RPE ranges. Values are (mean \pm SD).

Trial	Predicted $\dot{V}O_2$ peak (ml.kg $^{-1}$.min $^{-1}$)			
Production 1	32 \pm 4	27 \pm 4	29 \pm 4	29 \pm 4
Production 2	32 \pm 4	29 \pm 4	30 \pm 5	31 \pm 4

Consistency of predicting peak power output

Limits of agreement (Bias \pm 1.96 \times SD difference) and intraclass correlation coefficients between measured and predicted peak power output from the three RPE ranges (i.e., 9-13, 9-15 and 9-17) during the first and second production trials are presented in Table 8.8.

Table 8.8: LoA and ICC between measured and predicted peak power output from the three RPE ranges (i.e., 9-13, 9-15 and 9-17) during the first and the second production trials.

Trial	LoA/ICC	RPEs 9-13	RPEs 9-15	RPEs 9-17
Production 1	LoA	-19 \pm 27	-14 \pm 21	-10 \pm 18
	ICC	0.47	0.69	0.79
Production 2	LoA	-13 \pm 30	-9 \pm 28	-5 \pm 23
	ICC	0.35	0.52	0.65

8.4 Discussion

Study 5a

Able-bodied participants tended to achieve a higher peak power output (although not statistically significant ($P = 0.155$)) compared to their paraplegic counterparts and consequently a higher peak absolute oxygen uptake ($2.25 \text{ L} \cdot \text{min}^{-1}$ and $1.99 \text{ L} \cdot \text{min}^{-1}$, respectively). This may be attributed to the fact that able-bodied participants were able to use their trunk and leg muscles for stabilisation and as a fulcrum from which to push (Hopman, 1994; Janssen and Hopman, 2005). However, paraplegic individuals elicited a higher peak heart rate compared to their able-bodied counterparts. This may in turn reflect that paraplegic individuals were able to sustain a higher power output especially when the significantly higher RER values are taken into consideration.

This study assessed the accuracy of predicting $\dot{V}\text{O}_{2\text{peak}}$ from POpeak during arm cranking exercise in able-bodied and paraplegic persons using the equation prescribed by the ACSM (2006). There was no significant difference between measured $\dot{V}\text{O}_{2\text{peak}}$ and predicted $\dot{V}\text{O}_{2\text{peak}}$, regardless of group. Intraclass correlation coefficient values between measured and predicted $\dot{V}\text{O}_{2\text{peak}}$ are high (≥ 0.94), regardless of group. Limits of agreement values are relatively small (1 ± 5) for able-bodied and paraplegic individuals. In other words, the potential error in a worst case scenario is 19% for paraplegic individuals and 21% for able-bodied participants.

Study 5b

This study assessed the accuracy of predicting peak power output from a perceptually-guided, graded exercise test in able-bodied participants during arm cranking exercise. There was a significant difference between measured and predicted peak power output from the three RPE ranges (i.e., 9-13, 9-15 and 9-17) during the first

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production trial and from RPEs 9-13 and 9-15 during the second production trial. In other words, predicted POpeak from the three RPE ranges was lower during the first and the second production trial compared to measured peak power output.

There were quite wide limits of agreement (Table 8.8) and low to moderate intraclass correlation coefficients (Table 8.8) between measured and predicted POpeak. Although the higher RPE range (i.e., RPEs 9-17) provided a more accurate prediction of POpeak compared to the lower ranges (i.e., 9-13 and 9-15), as reflected by narrower LoA (Table 8.8) and closer means between measured and predicted POpeak (Table 8.6), the second perceptually-guided, exercise test did not provide a more accurate prediction of peak power output.

These findings are not in agreement with previous research which utilised the production mode of the RPE to predict maximal functional capacity during leg cycling and running on treadmill in healthy able-bodied individuals (Eston et al., 2005, 2006, 2008; Faulkner et al., 2007, 2009; Morris et al., 2009, 2010). However, the lower predictions of peak power output confirm our findings in study 4. In that study, we observed that prediction of peak functional capacity was lower compared to measured $\dot{V}O_2$ peak values in able-bodied participants. On the other hand, there was no significant difference between measured and predicted $\dot{V}O_2$ peak using the production mode of the RPE in paraplegic individuals (study 4). These findings may be partially attributed to the possibility, as indicated in study 4, that able-bodied participants may not be as familiar with arm cranking exercise compared to those with paraplegia.

8.5 Conclusion

Study 5a

It can be concluded that $\dot{V}O_2$ peak can be predicted with reasonable accuracy from POpeak using the equation described by the ACSM, (2006). This was evident regardless of group (the potential error was ~ 20% for both groups). The main

advantage of these findings is that $\dot{V}O_2$ peak can be estimated for large groups of people as arm crank ergometry is generally available in gym settings (Sawka, 1986; Jacobs and Nash, 2004). In addition, estimating $\dot{V}O_2$ peak from POpeak is less costly compared to measuring $\dot{V}O_2$ peak using gas analysers. However, it should be borne in mind that the actual direct measurement of $\dot{V}O_2$ peak is preferred for accuracy, where possible, as there was a margin error of $1 \pm 5 \text{ ml.kg}^{-1}.\text{min}^{-1}$ for able-bodied and paraplegic individuals.

Study 5b

In this study, the estimation of predicted peak power output from the three RPE ranges (i.e., 9-13, 9-15 and 9-17) was lower compared to measured POpeak in able-bodied participants during arm cranking exercise. Although these observations are not in agreement with previous research in this area (Eston et al., 2005, 2006, 2008; Faulkner et al., 2007, 2009; Morris et al., 2009, 2010), these findings are not surprising as able-bodied participants may be less familiar with arm exercise compared to paraplegic individuals. This seems true especially when considering that none of these participants were arm-trained (i.e., swimmer, kayaker and rowers).

The accuracy of predicting peak oxygen uptake from sub-maximal RPE is moderated by participants' group (i.e., able-bodied and paraplegic) during arm cranking exercise. In other words, people who are more familiar with arm work may be more accurate in gauging their exercise intensity using the RPE. This in turn will lead to a more accurate prediction of $\dot{V}O_2$ peak. Therefore, the aim of the next study was to explore the relationship of the RPE with proportion of time completed or proportion of time remaining to volitional exhaustion while exercising at constant-load intensity during arm cranking in able-bodied and paraplegic participants. A secondary aim of the next study was to assess whether the scalar property of the RPE would be moderated

Chapter 8: Prediction of Peak Oxygen Uptake Using the ACSM Equation & Prediction of
POpeak Using the Production Mode of the RPE

by exercise mode (i.e., arm cranking) since all the studies in this area have been
conducted during leg cycling and running/walking

Chapter nine

Study 6

Rating of perceived exertion during two different constant-load exercise intensities during arm cranking in able-bodied and paraplegic participants

Data from this chapter have contributed to:

Publication:

Harran Al-Rahamneh and Roger Eston (2010). Rating of perceived exertion during two different constant-load exercise intensities during arm cranking in paraplegic and able-bodied participants. *European Journal of Applied Physiology*.

Oral presentation:

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Poster presentation:

Harran Al-Rahamneh and Roger Eston. Rating of perceived exertion during heavy and severe constant-load exercise in able-bodied and paraplegic participants. ECSS Conference 2010, Antalya, Turkey.

9.1 Introduction

Several studies have observed that during prolonged sub-maximal exercise to exhaustion, the Rating of Perceived Exertion (RPE) rises as a linear function of the percentage of total exercise duration. This was first observed by Horstman et al. (1979) in a study which required participants to walk or run at 80% of maximal functional capacity to ‘self imposed exhaustion’. Noakes (2004) observation that the RPE data from the study by Baldwin et al. (2003) rose as a linear function of the duration of exercise that remained has inspired several studies to explore the phenomenon during running and cycling in able-bodied individuals (Eston et al., 2007; Crewe et al., 2008; Faulkner et al., 2008; Joseph et al., 2008). These studies have confirmed the original findings of Horstman et al. (1979). In this regard, it has been observed that the rate of increase in the RPE during self-paced (Faulkner et al., 2008; Joseph et al., 2008) or constant-load tasks (Eston et al., 2007; Crewe et al., 2008), where the participant exercises until volitional exhaustion or to a maximal or near-maximal RPE, is proportional to the time remaining on the task. In other words, when the RPE is expressed against the proportion (%) of the time completed, the rate of change in the RPE is similar. The scalar relationship between the RPE and time to volitional exhaustion, when exercising at a constant sub-maximal load during arm exercise in able-bodied and paraplegic individuals, is yet to be determined.

It is well established that arm exercise elicits lower peak values for heart rate (HR), oxygen uptake ($\dot{V}O_2$), ventilation (\dot{V}_E) and power output (PO) compared to leg cycling (Franklin et al., 1983; Vander et al., 1984; Aminoff et al., 1996). However, HR, $\dot{V}O_2$, \dot{V}_E , RPE and blood lactate level are higher at sub-maximal levels of arm exercise compared to leg cycling (Franklin et al., 1983; Vander et al., 1984; Eston and Brodie, 1986; Borg et al., 1987). Therefore, it would be of interest to assess whether exercising with a smaller muscle mass (the arms) would affect the scalar property of the RPE.

Jacobs et al. (1997) and Lewis et al. (2007) reported poor relationships between the RPE and $\dot{V}O_2$ in individuals with spinal cord injury (SCI) during exercise involving functional neuromuscular stimulation and discontinuous, incremental arm cranking exercise, respectively. This would imply that the utility of the RPE is limited when applied with such populations. However, Goosey-Tolfrey et al. (2010) observed similar HR, $\dot{V}O_2$ and blood lactate levels during exercise intensities set at 50% and 70% $\dot{V}O_{2\text{peak}}$ compared to when the RPE from the two intensities was used to regulate exercise in well trained paraplegic men. Müller et al. (2004) also observed similar RPE during two identical wheelchair exercise tests of 5 x 1500m in eleven wheelchair racers. These equivocal findings regarding the utility of the RPE in individuals with SCI might be attributed to the physical activity level of participants. The studies by Müller et al. (2004) and Goosey-Tolfrey et al. (2010) employed well trained subjects, whereas, the studies by Jacobs et al. (1997) and Lewis et al. (2007) were based on less active participants. In addition, the study by Jacobs et al. (1997) employed shuttle-walking exercise using functional neuromuscular stimulation which might in turn affect the participants' ability to accurately appraise their RPE during exercise involving muscle groups below the lesion level.

The current study compared a) the relationship between RPE and time to volitional exhaustion while exercising at two different constant-load exercise intensities in able-bodied and paraplegic persons, and b), the rate of change in RPE (*beta coefficient*) when regressed against time and %time to volitional exhaustion between the two constant-load exercise intensities. We hypothesised that a linear relationship between the RPE and time to volitional exhaustion would be evident during both exercise intensities, irrespective of participants' group. We also expected that the rate of change in the RPE, expressed as the proportion of the time to volitional exhaustion, would be similar between the two exercise intensity conditions, regardless of participants' group.

9.2 Methods

Participants

Ten able-bodied men volunteered to take part in the study (Table 9.1). Able-bodied participants were sport science students studying at the University of Exeter. Regarding those men with paraplegia, six had lower limbs flaccid paralysis as a result of poliomyelitis infection, and four had SCI with neurological levels at T6 and below (i.e., T6 to L1) with duration since injury ranged between 4 to 25 years. Able-bodied participants were physically active (> 3 h per week), but not specifically arm-trained (e.g., swimmer). Persons with paraplegia were physically active (> 3 h per week) and participated in such sports as wheelchair basketball, weightlifting and wheelchair racing at both professional and recreational levels.

Table 9.1: Participant characteristics and relative disability descriptions and mean \pm SD for groups

Participants	Age (years)	Height (cm)	Weight (kg)	Type of lesion	Lesion level	Years since injury
Para 1	34.0	160	69.0	Polio	-	-
Para 2	34.8	170	60.0	Polio	-	-
Para 3	31.0	165	59.8	SCI	T6 incomplete	25.0
Para 4	33.0	173	58.2	Polio	-	-
Para 5	31.2	178	82.0	Polio	-	-
Para 6	41.2	169	53.5	Polio	-	-
Para 7	29.1	180	83.5	SCI	L1 complete	8.5
Para 8	29.9	170	49.4	SCI	T7 complete	19.5
Para 9	22.1	167	53.3	SCI	T11complete	4.1
Para 10	38.3	160	64.6	Polio	-	-
Mean \pm SD	32.4 ± 5.3	169.2 ± 6.7	63.3 ± 12.1	-	-	-
Able-bodied						
Mean \pm SD	25.7 ± 3.0	173.3 ± 5.3	75.2 ± 13.5	-	-	-

Please see section (3.1 *Measurement of height and body mass*) for more details about how height and body mass were measured. This study was conducted with joint institutional ethics approval from the University of Jordan and the University of Exeter. Testing for all able-bodied participants took place in the School of Sport and

Health Sciences at the University of Exeter. All exercise tests for paraplegic individuals took place in the Faculty of Physical Education at the University of Jordan.

Procedures

All participants performed four exercise tests. In the first two visits to the laboratory, the participant performed a ramp exercise test to determine peak functional capacity and to determine the gas exchange threshold (see section *3.5 Ramp exercise test, Arm cranking ramp exercise test (study 3 & 6)*) and a graded exercise test (see section *(Graded exercise test (study 3, 4, 5a, 5b & 6))* to ascertain true peak values (i.e., $\dot{V}O_{2\text{peak}}$ and HRpeak). These two exercise tests were conducted in counterbalanced order in order to avoid an ordering effect. Data from the ramp exercise test were also used to determine the constant-load exercise intensities for the two sub-maximal tests. The constant-load exercise tests were each performed to volitional exhaustion at 50% and 70% Δ (i.e., the difference between the gas exchange threshold “GET” and POpeak). These two constant-load exercise tests were conducted in a counterbalanced order and separated by 48-h. Please see section (*3.9 Constant-load exercise tests*) for more details about the constant-load exercise tests. Participants were asked to avoid moderate and heavy exercise intensities prior to and between the exercise tests.

All exercise tests were performed on the same Lode arm ergometer (see section *(3.4 Arm ergometry, Study 3, 4, 5a, 5b & 6)*). For gas analysis please see section *(3.3 Gas analysis, Study 3, 4, 5a & 6)*. Participants reported their RPEo and RPEp at the completion of the exercise tests and in the remaining 20 s of each minute and each stage during the ramp exercise test and the GXT, respectively. However, the RPEo and RPEp were collected at random times during the two constant-load exercise tests and at the termination of the exercise test. This was done to avoid giving the participants information about the duration of time that had elapsed. RPEo was collected first.

Data analysis

A series of two-factor, mixed model ANOVAs (Test; ramp and GXT x Group; able-bodied and paraplegic) were used to compare $\dot{V}O_2$ peak, HRpeak and POpeak responses observed at the termination of the ramp exercise test and the GXT and between groups. Linear regression analyses were used to determine the individual relationships " R^2 " between time to exhaustion (X axis) and the RPE (Y axis). As it has been shown that the data are not normally distributed in correlation coefficients (Thomas et al., 2005), the R^2 values were converted to Fisher Zr to approximate for the normality of data distribution. Furthermore, a two factor ANOVA (Intensity; 50% and 70% Δ x Group; able-bodied and paraplegic) was used to compare time to exhaustion at 50% and 70% Δ and between groups.

Two factor ANOVAs (Intensity; 50% and 70% Δ x Group; able-bodied and paraplegic) were used to compare the rate of change of the RPE (*b coefficient*) between 50% and 70% Δ when the RPE was regressed against time and proportion of time (%time) to exhaustion. In addition, three factor ANOVAs (Intensity; 50% Δ and 70% Δ ; Time; 2 minutes in the exercise test and termination of the exercise test x Group; able-bodied and paraplegic) were used to compare % $\dot{V}O_2$ peak and %HRpeak observed at 2 minutes in the exercise and at the termination of the exercise test and whether exercise intensity and/or participants' group moderated these findings. Finally, two factor ANOVAs (RPE; RPEo and RPEp x Group; able-bodied and paraplegic) was used to assess whether there was a difference between RPEo and RPEp values observed at the termination of 50% Δ and 70% Δ and between groups. The assumptions of sphericity for all tests were checked using the Mauchly' test; where sphericity assumptions were not confirmed, the Greenhouse-Geisser epsilon was used to correct the degrees of freedom (Winter et al., 2001; Field, 2009). Alpha was set at P 0.05 and adjusted accordingly. Data were analysed using SPSS for Windows, PC software, version 16.

9.3 Results

Descriptive statistics of the maximal exercise tests

The peak physiological (i.e., $\dot{V}O_2$, HR, RER and \dot{V}_E), perceptual (i.e., RPEo and RPEp) and physical (i.e., PO) values observed at the termination of the ramp exercise test and the GXT are presented in Table 9.2.

Table 9.2: Peak values observed at the termination of the ramp exercise test and the GXT for able-bodied and paraplegic individuals. Values are (mean \pm SD).

Group/ Exercise	$\dot{V}O_2$ peak (L.min $^{-1}$)	$\dot{V}O_2$ peak (ml.kg $^{-1}$.min $^{-1}$)	HRpeak (b.min $^{-1}$)	\dot{V}_E peak (L.min $^{-1}$)	RER	POpeak (W)	RPEo	RPEp
Able-bodied GXT	2.58 \pm 0.37	35 \pm 7°	170 \pm 13	102 \pm 17	1.13 \pm 0.05	117 \pm 14°	17.9 \pm 1.5	19.5 \pm 0.7
Able-bodied Ramp	2.41 \pm 0.31	33 \pm 5*°	159 \pm 12*	89 \pm 18	1.16 \pm 0.06	137 \pm 11*°	17.5 \pm 1.5	19.6 \pm 0.7
Paraplegic GXT	2.00 \pm 0.41	32 \pm 5	172 \pm 11	80 \pm 13	1.24 \pm 0.08	95 \pm 20	18.6 \pm 1.0	19.2 \pm 0.9
Paraplegic Ramp	1.89 \pm 0.43	30 \pm 5*	163 \pm 13*	70 \pm 16	1.24 \pm 0.08	108 \pm 20*	18.4 \pm 1.2	19.4 \pm 1.0

* Significant difference between ramp exercise test and GXT $P < 0.05$

°Significant difference between able-bodied and paraplegic individuals $P < 0.05$

Participants achieved a significantly higher $\dot{V}O_2$ peak during the GXT compared to the ramp exercise test ($F_{(1, 18)} = 21.3, P < 0.001$). Able-bodied participants achieved significantly higher $\dot{V}O_2$ peak compared to their paraplegic counterparts ($F_{(1, 18)} = 10.6, P < 0.01$). However, there was no significant test x group interaction on $\dot{V}O_2$ peak ($F_{(1, 18)} = 0.6, P > 0.05$). Similar analyses showed that participants achieved a significantly higher HRpeak during the GXT compared to the ramp exercise test ($F_{(1, 18)} = 18.9, P < 0.05$). There was no significant difference in HRpeak between able-bodied and paraplegic participants ($F_{(1, 18)} = 0.4, P > 0.05$) and no significant test x group interaction on HRpeak ($F_{(1, 18)} = 0.3, P > 0.05$). Further analysis showed that participants achieved a significantly higher POpeak during the ramp exercise test compared to the GXT ($F_{(1, 18)} = 69.0, P < 0.001$) and able-bodied participants achieved a significantly higher POpeak compared to paraplegic individuals ($F_{(1, 18)} = 12.7, P < 0.01$). There was no significant test x group interaction on POpeak ($F_{(1, 18)} = 2.2, P > 0.05$).

Descriptive statistics of the constant-load exercise tests

Time to exhaustion, PO, the relationship (R^2) between RPEo and time to volitional exhaustion and between RPEp and time to volitional exhaustion for both exercise intensities (50% and 70% Δ) and for both groups are presented in Table 9.3.

Table 9.3: Power output (PO), time to exhaustion, the relationship (R^2) between RPEo and time to exhaustion and between RPEp and time to exhaustion for 50% and 70% Δ exercise intensities and for able-bodied and paraplegic participants

Group/ Exercise	PO (W)	Time to exhaustion (minutes)	R^2 (RPEo and time)	R^2 (RPEp and time)
Able-bodied 50% Δ	82 ± 9	$27.0 \pm 15.0^{\circ}$	0.88	0.89
Able-bodied 70% Δ	99 ± 10	9.4 ± 2.6	0.92	0.93
Paraplegic 50% Δ	65 ± 16	$14.6 \pm 5.9^*$	0.92	0.89
Paraplegic 70% Δ	78 ± 17	8.0 ± 2.5	0.94	0.92

* Significant difference between 50% and 70% Δ $P < 0.05$

\circ Significant difference between paraplegic and able-bodied individuals $P < 0.05$

Two factor ANOVA showed that participants, regardless of group, exercised for a significantly longer duration at 50% compared to 70% Δ ($F_{(1, 18)} = 29.0, P < 0.001$). Able-bodied participants exercised for significantly longer duration compared to those with paraplegia ($F_{(1, 18)} = 6.0, P < 0.05$). Finally, there was a significant intensity x group interaction on exercise duration ($F_{(1, 18)} = 6.0, P < 0.05$). Tukey's HSD showed that able-bodied participants exercised for significantly longer duration during the constant-load exercise test at 50% Δ compared to paraplegic individuals ($P < 0.05$).

The rate of change of the RPE (b coefficient) between 50% and 70% Δ

Two factor ANOVAs revealed that the rate of change of RPEo was significantly greater when regressed against absolute time for the constant-load exercise intensity equating to 70% Δ ($b = 1.10 \pm 0.58$) compared to 50% Δ ($b = 0.53 \pm 0.45$), ($F_{(1, 18)} = 59.5, P < 0.001$). Paraplegic individuals had a significantly greater rate of change in the RPEo compared to their able-bodied counterparts ($F_{(1, 18)} = 6.8, P < 0.05$). There was no significant intensity x group interaction on the rate of change in RPEo ($F_{(1, 18)} = 0.3, P > 0.05$). Similar analyses showed a significantly greater rate of change in RPEp when regressed against absolute time for the constant-load exercise intensity equating to 70% Δ ($b = 1.10 \pm 0.63$) compared to 50% Δ ($b = 0.53 \pm 0.45$), ($F_{(1, 18)} = 53.1, P < 0.001$). Paraplegic individuals had a significantly greater rate of change in the RPEp compared to their able-bodied counterparts ($F_{(1, 18)} = 5.9, P < 0.05$). There was no significant intensity x group interaction on the rate of change in RPEp ($F_{(1, 18)} = 0.2, P > 0.05$). Figures 9.1 and 9.2 elucidate the rate of change in RPEp against time to volitional exhaustion in able-bodied and paraplegic individuals, respectively.

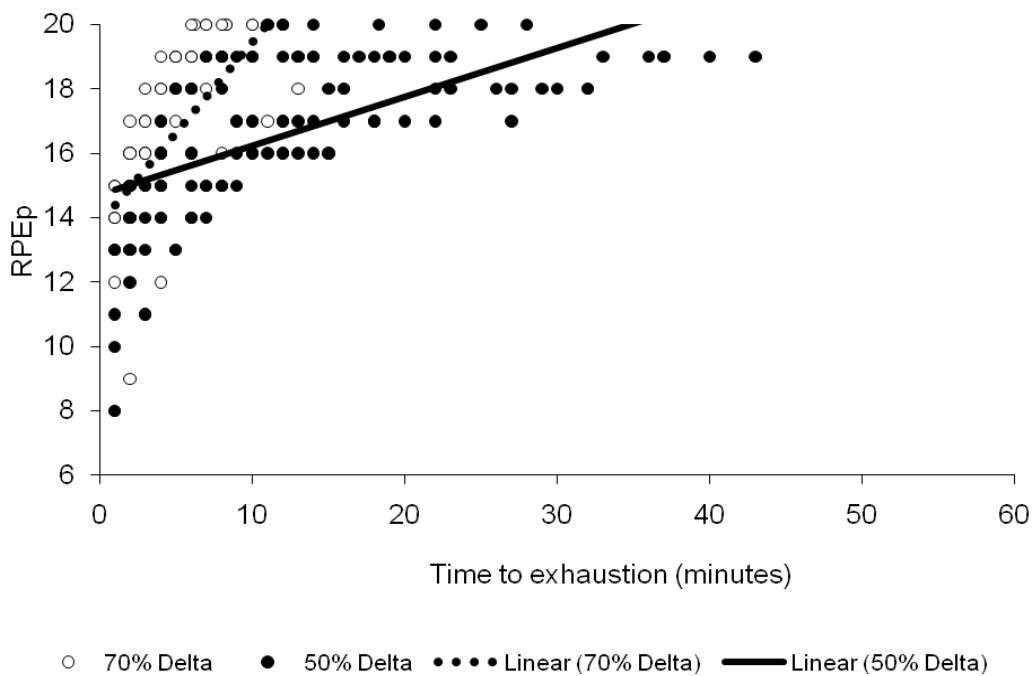


Figure 9.1: The rate of change of the RPEp when regressed against time to exhaustion during both constant-load exercise intensities in able-bodied participants

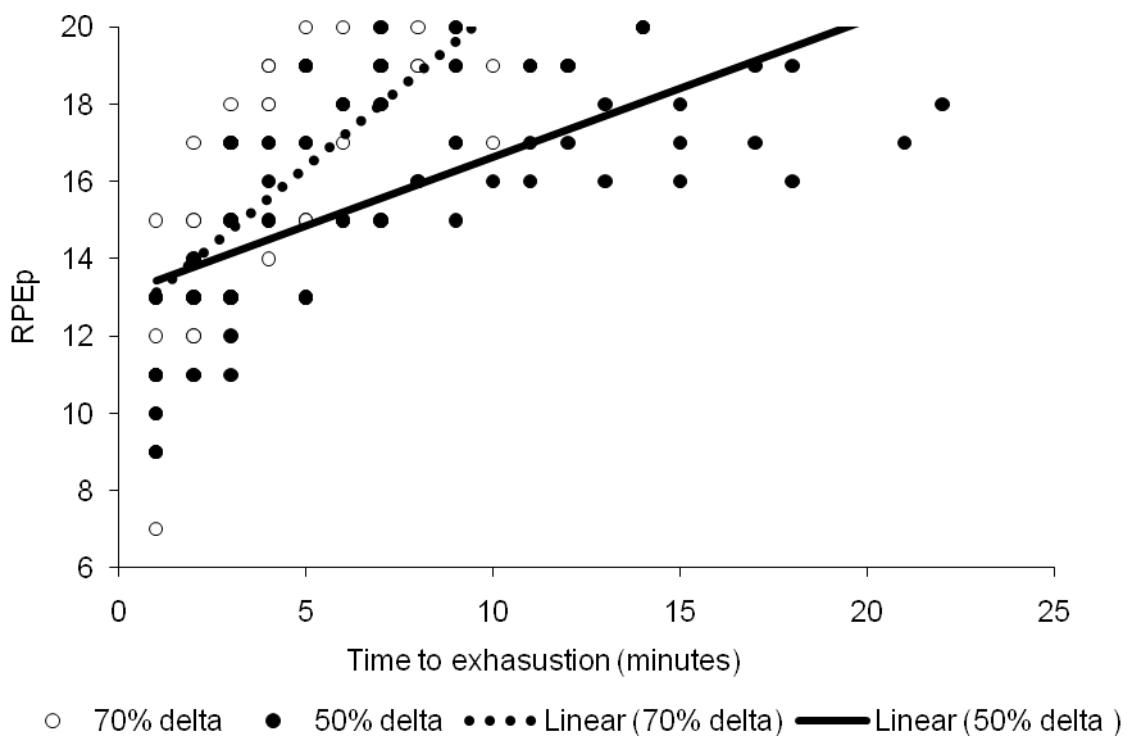


Figure 9.2: The rate of change of the RPEp when regressed against time to exhaustion during both constant-load exercise intensities in paraplegic individuals

All differences in the rate of change in RPEo and RPEp between the two constant-load exercise tests at 70% Δ and 50% Δ and between able-bodied and

paraplegic individuals were removed when the RPE_o and RPE_p were regressed against proportion of time (%time) to volitional exhaustion (all $P > 0.05$). Figures 9.3 and 9.4 elucidate the rate of change in RPE_p against %time to volitional exhaustion in able-bodied and paraplegic individuals, respectively.

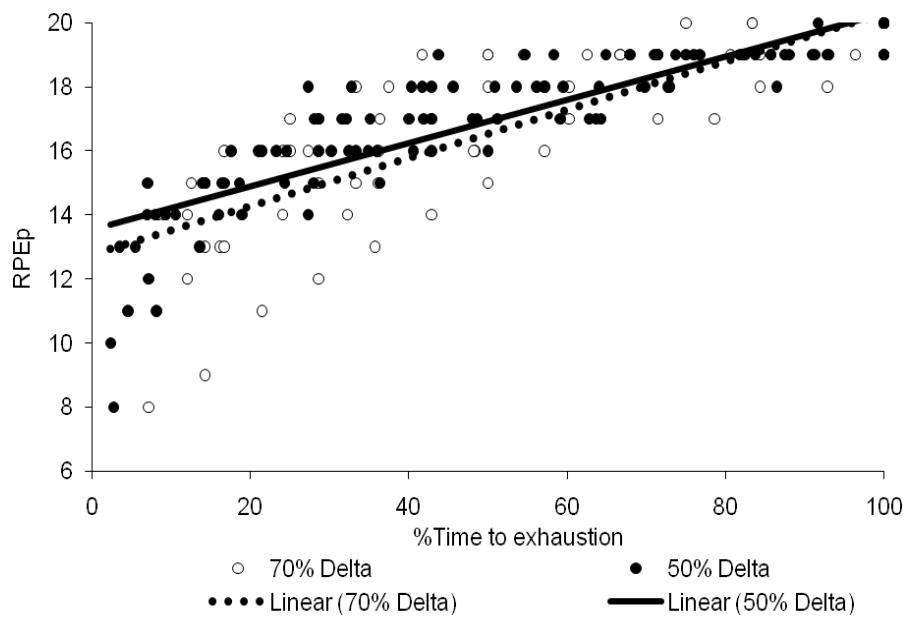


Figure 9.3: The rate of change of the RPE_p when regressed against %time to exhaustion during both constant-load exercise intensities in able-bodied participants

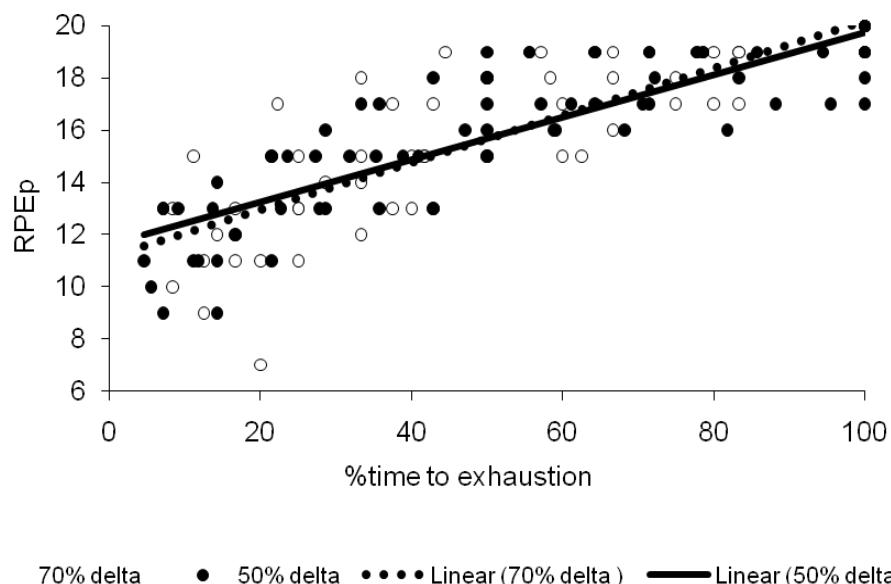


Figure 9.4: The rate of change of the RPE_p when regressed against %time to exhaustion during both constant-load exercise intensities in paraplegic individuals

Physiological comparison between 50% and 70% Δ

The physiological (i.e., % $\dot{V}O_2$ peak, %HRpeak and RER) variables observed at 2 minutes in the exercise and at the termination of the exercise test for both exercise intensities at 50% Δ and 70% Δ for able-bodied and paraplegic individuals are presented in Table 9.4. Overall RPE and peripheral RPE were collected at random times during both constant-load exercise intensities. Therefore, as most of the participants were asked to report their RPE for the first time at 2 minutes in the exercise, 2 minutes in the exercise and the end of the exercise were chosen to detect the differences in physiological and perceptual responses between the beginning and the termination of the exercise tests.

Table 9.4: The physiological variables observed at 2 min in the exercise and at the termination of the constant-load exercise tests at 50% and 70% Δ for able-bodied and paraplegia individuals. Values are (mean ± SD).

Group	% $\dot{V}O_2$ peak	% $\dot{V}O_2$ peak	%HRpeak	%HRpeak	RER	RER
	2 min	final	2 min	final	2 min	final
Able-bodied 50% Δ	73 ± 14	81 ± 11*	76 ± 9	92 ± 7*	1.07 ± 0.03	0.98 ± 0.05
Able-bodied 70% Δ	72 ± 15	92 ± 9*°	75 ± 6	97 ± 4*°	1.09 ± 0.04	1.06 ± 0.05
Paraplegic 50% Δ	75 ± 7	85 ± 6*	78 ± 6	89 ± 6*	1.07 ± 0.08	1.03 ± 0.02
Paraplegic 70% Δ	80 ± 6	96 ± 4*°	79 ± 7 ⁺	94 ± 5*°	1.07 ± 0.03	1.18 ± 0.12

* Significant difference between 2 min in the exercise and termination of the exercise test $P < 0.05$

° Significant difference between 50 Δ and 70 Δ $P < 0.05$

⁺ Significant difference between able-bodied and paraplegic individuals $P < 0.05$

Three factor ANOVA revealed that participants exercised at significantly higher % $\dot{V}O_2$ peak during the exercise test at 70% Δ compared to 50% Δ % ($F_{(1, 18)} = 16.6, P < 0.01$). There was no significant difference between able-bodied and paraplegic individuals in % $\dot{V}O_2$ peak ($F_{(1, 18)} = 2.0, P > 0.05$). The exercise test was terminated at a significantly higher % $\dot{V}O_2$ peak compared to % $\dot{V}O_2$ peak at 2 min in the exercise ($F_{(1, 18)} = 38.3, P < 0.001$). There was no significant intensity x group interaction on % $\dot{V}O_2$ peak ($F_{(1, 18)} = 0.7, P > 0.05$) and no significant time x group interaction on % $\dot{V}O_2$ peak ($F_{(1, 18)} = 0.03, P > 0.05$). However, there was a significant intensity x time x interaction on % $\dot{V}O_2$ peak ($F_{(1, 18)} = 17.5, P < 0.01$) and a significant intensity x time x

group interaction on % $\dot{V}O_2$ peak ($F_{(1, 18)} = 4.9, P < 0.05$). Tukey's HSD revealed similar % $\dot{V}O_2$ peak at 2 min in the exercise during both exercise intensities, but significantly higher % $\dot{V}O_2$ peak at the termination of the exercise test for 70% Δ compared to 50% Δ exercise test ($P < 0.05$).

Similar analysis revealed that participants exercised at significantly higher %HRpeak during the exercise test at 70% Δ compared to at 50% Δ ($F_{(1, 18)} = 5.0, P < 0.05$). Although participants terminated the exercise test at significantly higher %HRpeak compared to %HRpeak at 2 min in the exercise ($F_{(1, 18)} = 320.4, P < 0.001$), there was no significant difference between able-bodied and paraplegic individuals in %HRpeak ($F_{(1, 18)} = 0.0, P > 0.05$). There was no significant intensity x group interaction on %HRpeak ($F_{(1, 18)} = 0.3, P > 0.05$) and no significant intensity x time x group on %HRpeak ($F_{(1, 18)} = 1.1, P > 0.05$). However, there was a significant time x group interaction on %HRpeak ($F_{(1, 18)} = 11.4, P < 0.01$) and a significant intensity x time interaction on %HRpeak ($F_{(1, 18)} = 14.1, P < 0.01$). Tukey's HSD revealed that paraplegic participants exercised at significantly higher %HRpeak at 2 min in the exercise during the constant-load exercise test at 70% Δ compared to their able-bodied counterparts ($P < 0.05$). Further Tukey's HSD showed that participants terminated the exercise test at significantly higher %HRpeak during 70% compared to 50% Δ ($P < 0.05$).

Comparison of RPE values reported at the termination of the constant-load tests

The perceptual (i.e., RPEo and RPEp) values observed at 2 in the exercise and at the termination of the exercise test during 50% Δ and 70% Δ for able-bodied and paraplegic individuals are presented in Table 9.5.

Table 9.5: The perceptual responses observed at 2 min and at the termination of the constant-load exercise tests at 50% and 70% Δ for able-bodied and individuals with paraplegia. Values are (mean \pm SD).

Group	RPEo 2 min	RPEo final	RPEp 2 min	RPEp final
Able-bodied 50% Δ	12.4 \pm 1.6	17.7 \pm 2.0	14.6 \pm 1.7	19.7 \pm 0.5°
Able-bodied 70% Δ	12.1 \pm 2.5	17.5 \pm 2.1	14.6 \pm 2.3	19.9 \pm 0.3°
Paraplegic 50% Δ	11.9 \pm 1.9	18.4 \pm 1.1	12.8 \pm 2.3	19.0 \pm 1.2°
Paraplegic 70% Δ	12.2 \pm 1.9	18.7 \pm 1.1	13.3 \pm 1.9	19.3 \pm 0.3

° Significant difference between RPEo and RPEp at the termination of the constant-load exercise tests $P < 0.05$

Two factor ANOVA showed that participants reported significantly higher RPEp compared to RPEo at the completion of the constant-load exercise test at 70% Δ ($F_{(1, 18)} = 20.0$, $P < 0.001$). Although there was no significant difference between groups ($F_{(1, 18)} = 0.4$, $P > 0.05$), there was a significant intensity x group interaction on RPE ($F_{(1, 18)} = 7.1$, $P < 0.05$). Tukey's HSD showed that able-bodied participants reported significantly higher RPEp than RPEo, but this difference was not significant for paraplegic individuals. Similar analysis revealed significantly higher RPEp compared to RPEo at the completion of the constant-load exercise test at 50% Δ ($F_{(1, 18)} = 13.1$, $P < 0.01$). There was no significant difference between groups ($F_{(1, 18)} = 3.8$, $P > 0.05$) and there was no significant exercise intensity x group interaction on RPE ($F_{(1, 18)} = 0.0$, $P > 0.05$). Overall and peripheral RPE values reported at 2 minutes in the exercise and at the termination of the constant-load exercise tests are shown in Table 9.4.

9.5 Discussion

This study assessed the relationship between the RPE (i.e. RPEo and RPEp) and time to volitional exhaustion while exercising at two different constant-load exercise intensities equal to 50% and 70% Δ in able-bodied and paraplegic individuals. We also assessed the rate of change of the RPEo and RPEp against absolute time and

%time to volitional exhaustion between the constant-load exercise tests at 50% and 70% Δ in these groups. The first main finding of this study is the strong linear relationship between the RPE and time to exhaustion during the constant-load exercise test at 50% Δ ($R^2 \geq 0.88$) and 70% Δ ($R^2 \geq 0.92$) for able-bodied and paraplegic individuals. This is in accordance with previous observations during running and cycling in able-bodied individuals (Horstman et al., 1979; Crewe et al., 2008). The second main finding is the significantly greater rate of change in the RPE during the constant-load exercise test at 70% Δ compared to 50% Δ when the RPE was regressed against time. However, these differences in the rate of change of the RPE disappeared when the RPE was regressed against %time. This observation is in agreement with previous research during running and cycling in able-bodied individuals (Noakes, 2004; Eston et al., 2007; Crewe et al., 2008; Faulkner et al., 2008; Joseph et al., 2008).

It has been suggested that ventilatory threshold and maximal lactate steady-state/critical power are better criteria to determine exercise intensity compared to $\dot{V}O_2$ peak alone (Katch et al., 1978; Jones et al., 2009). Katch et al. (1978) observed that at exercise equal to 80% HRpeak 17 out of 31 individuals were exercising above the $\dot{V}O_2$ at anaerobic threshold and the other 14 participants were exercising below the $\dot{V}O_2$ at anaerobic threshold. Therefore, the ventilatory threshold and POpeak were used to determine the two different constant-load exercise intensities in this study. It has also been indicated that exercise in the severe domain is limited and predictable (Jones et al., 2009) which was the case during the constant-load exercise test at 70% Δ. Furthermore, the stronger relationship (although non-significant) between the RPE and time to exhaustion at 70% Δ compared to 50% Δ supports the notion by Noakes (2008) which stated that the RPE property to predict time to exhaustion to be stronger at higher intensities.

During the constant-load exercise test at 50% Δ, participants did not reach $\dot{V}O_2$ peak and the time to exhaustion was significantly longer than at 70% Δ (i.e., heavy domain). Able-bodied participants exercised for a significantly longer duration at 50% Δ

compared to their paraplegic counterparts. This may reflect the fact that paraplegic individuals are not used to constant-load tasks as they do not push their wheelchairs constantly (i.e., the pushing action on the wheelchair is intermittent in nature (Sawka et al., 1980; Vanlandewijck et al., 1994)). This observation may also be attributable to the able-bodied participants being able to use their lower limbs for stabilization and as a fulcrum from which to push (Janssen and Hopman 2005). This would have helped them to exercise for longer durations, especially when considering that participants did not achieve their $\dot{V}O_2$ peak or HRpeak at this exercise intensity.

It is important to note that participants reported peak RPEp ($RPE_p \geq 19.0$) at the termination of the constant-load exercise tests. This is in accordance with previous research at both constant work rate exercise tests (Horstman et al., 1979; Eston et al., 2007) or graded exercise tests to volitional exhaustion to measure peak functional capacity in able-bodied (Faulkner and Eston, 2007; Lambrick et al., 2009) and paraplegic individuals (study 1). Regardless of group, all participants reported a higher RPEp at the termination of the exercise tests compared to RPEo. The higher RPEp compared to RPEo are in accordance with previous research by Demura and Nagasawa (2003) and Faulkner and Eston (2007). This might be attributed to the smaller muscle mass activated during the arm exercise (Borg et al., 1987; McArdle et al., 2007) and consequently the higher work per unit of contracting muscle mass (Åstrand et al., 2003).

9.5 Conclusion

This study showed that there is very strong linear relationship between the RPE (both RPEo and RPEp) and time to volitional exhaustion at constant-load exercise intensities during arm exercise in able-bodied and paraplegic individuals. It also showed that RPE increased at significantly higher rate of change during the constant-load exercise test at 70% Δ compared to 50% Δ when the RPE was regressed against time. However, these differences in the rate of change in the RPE between the two constant-load exercise intensities disappeared when the RPE was regressed against %time. These findings are in accordance with previous studies which have shown that

the RPE scales with time while exercising at constant work rate under different conditions during leg cycling in healthy able-bodied participants (Noakes, 2004; Eston et al., 2007). As such, this study confirms that the RPE scales with time while exercising at a constant work rate during arm cranking exercise in healthy able-bodied and paraplegic participants. This may indicate that the RPE is set at the beginning of the exercise and increases as a proportion of time completed or remaining regardless of the size of the muscle mass activated during exercise. This study has important implications for using the RPE as a sensitive predictor of time to exhaustion. These findings also have important implications for instructors who work with paraplegic persons in rehabilitation settings. For example, if the participant reports an RPE of 15 or 17 at the beginning of exercise, the instructor should decrease the work rate to allow this person to complete the desired duration (e.g., 30 minutes). In contrast, if the participant reports an RPE of 10 or 11 in the second or the third part of the exercise, the exercise instructor should increase the work rate in order to allow this person to gain the desired cardiovascular adaptations.

Chapter ten

General discussion

The aim of the following section is to combine, discuss and interpret the main findings of the six studies contained in this thesis. These findings are sub-headed to facilitate and summarise the main points and implications from the studies.

The aims of the thesis were to assess:

- The strength of the relationship between the RPE and physical and physiological markers of exercise intensity during arm cranking exercise in able-bodied and paraplegic individuals.
- The accuracy of predicting $\dot{V}O_2$ peak from sub-maximal RPE and $\dot{V}O_2$ values when extrapolated to RPE of 20 (maximal RPE) using both *estimation* and *production* procedures in able-bodied and paraplegic individuals.
- The scalar property of the RPE during arm cranking exercise while exercising at two different constant-load exercise intensities in able-bodied and paraplegic individuals.

Before assessing these three aims, we were interested in comparing some of the physical and physiological variables observed at the termination of the exercise test between arm cranking exercise and leg cycling, between male and female and between able-bodied and paraplegic individuals.

10.1 Comparison of physical and physiological variables observed at the completion of the exercise test

Arm cranking vs. leg cycling

At a maximal level of exercise, able-bodied participants, irrespective of gender, achieved lower peak values for power output, oxygen uptake, minute ventilation and heart rate during arm cranking exercise compared to leg cycling. These findings are in accordance with previous research which compared the peak cardiorespiratory values elicited during arm versus leg exercise (Franklin et al., 1983; Vander et al., 1984; Aminoff et al., 1996; Muraki et al., 2004). Generally speaking, this might be attributed to

the smaller muscle mass activated during arm exercise compared to leg cycling (Eston and Brodie, 1986; Borg et al., 1987; McArdle et al., 2007). However, similar values were observed for ratings of perceived exertion and blood lactate concentration at the termination of the exercise test for both modes of exercise. These observations are in agreement with the findings by Franklin et al. (1983) and Vander et al. (1984) in both men and women participants. The similar RPE values might be attributed to the fact that participants often reach their peak RPE (i.e., RPE 19) or maximal RPE (i.e., RPE20) values at the termination of the maximal exercise test during both modes of exercise.

At sub-maximal levels of exercise, it is well established that arm exercise elicits higher values for $\dot{V}O_2$, heart rate, \dot{V}_E , blood lactate concentration and RPE at a given work rate or proportion of $\dot{V}O_2\text{peak}$ (% $\dot{V}O_2\text{peak}$) compared to leg cycling (Franklin et al., 1983; Vander et al., 1984; Eston and Brodie, 1986; Borg et al., 1987). The higher sub-maximal $\dot{V}O_2$ values might be attributed to the lower mechanical efficiency during arm exercise as a result of recruiting additional muscle groups to stabilise the torso and from static work of other muscle groups which do not contribute to the external work rate (Bevegard et al., 1966., Eston and Brodie, 1986; McArdle et al., 2007).

Higher sub-maximal values for heart rate and \dot{V}_E have been attributed to the higher sympathetic outflow during arm exercise compared to leg cycling (Bevegard et al., 1966; Davies et al., 1974). Other factors which may elevate sub-maximal heart rate during arm exercise are the lower stroke volume owing to reduced venous return due to orthostatic position (Stenberg et al., 1967) and an inadequate or constrained muscle pumping mechanism (Davies and Sargeant, 1974). Other factors which may increase sub-maximal \dot{V}_E during arm exercise are the degree of synchronization between rhythmic movements of the arms and the respiratory rate (Vokac et al., 1975; Mangum, 1984) and the limitation of tidal volume, as a result of static movement of the abdominal, pectoralis and other muscles in the torso and shoulder girdle (Mangum, 1984). It has been indicated that the higher sub-maximal \dot{V}_E during arm exercise is an

important factor in maintaining stroke volume in the absence of muscle pumping mechanism (Bevegard et al., 1966).

Ramp vs. graded exercise test

Participants, regardless of group (i.e., able-bodied and paraplegic), achieved a higher peak power output during the ramp exercise test compared to the graded exercise test. However, the duration of the ramp exercise test was shorter compared to the GXT. These findings are in accordance with previous research during leg cycling in able-bodied participants (Boone et al., 2010). These findings have important implications during arm cranking exercise for able-bodied and paraplegic individuals, as this form of incremental exercise testing will minimise the effect of localised fatigue and consequently the effects of this in terminating the exercise test, compared to the GXT. Nevertheless, both groups achieved higher peak values for heart rate and $\dot{V}O_2$ during the GXT compared to the ramp exercise test. This may be attributed to the fact that more time is spent at each stage during the GXT, which in turn allows enough time for the heart rate and $\dot{V}O_2$ to reach steady-state at each stage compared to the ramp exercise test where the work rate is typically increased in a rapid way (e.g., 1 W every 4 s or 1 W every 2 s).

Therefore, if the aim of the exercise test is to measure POpeak, the ramp exercise test should be employed as the GXT will underestimate POpeak due to localised fatigue in the arms. This is important as exercise scientists who work with paraplegic people, especially those in rehabilitation settings, are usually interested in measuring work rate more than physiological variables (i.e., $\dot{V}O_2$ and heart rate). The rationale for this is that work rate is a more reflective measure of daily living activities such as wheelchair propulsion and hand cycling.

Gender effects

Regardless of the exercise mode (i.e., arm cranking and leg cycling) or group (i.e., able-bodied and paraplegic), the men in these studies achieved considerably higher peak values for power output, oxygen uptake and ventilation compared to their

women counterparts. These findings are in agreement with previous research (Franklin et al., 1983; Vander et al., 1984; Robertson et al., 2000; Faulkner et al., 2007). The higher peak power output may be attributed to the fact that men have more muscle mass (38.4% vs. 30.6%, respectively; Janssen et al., 2000) and less percentage of body fat (15% vs. 25%, respectively; McArdle et al., 2007) compared to women. The higher $\dot{V}O_2$ peak is most likely attributed to the fact that women have lower peak values for stroke volume and cardiac output owing to their smaller body size, blood volume, heart and lower haemoglobin compared to men (Wilmore, 2005; McArdle et al., 2007). Finally, the higher peak ventilation values for men compared to women is most likely attributed to the fact that men have a larger thoracic cavity due to the enlarged rib cage which enable them to accommodate greater quantities of air (Eston and Romer, 2009).

Able-bodied vs. paraplegic

Able-bodied men achieved higher peak values for power output, oxygen uptake and ventilation compared to their paraplegic counterparts. These findings are in accordance with previous research by Zwieren and Bar-Or, (1975) and Hopman et al. (1992). The higher peak power output values are most likely attributed to the fact that able-bodied men were able to use the trunk and the lower limbs for stabilization and as a fulcrum from which to push (Hopman et al., 1992; Hopman, 1994; Janssen and Hopman, 2005). As oxygen uptake is a function of power output, the higher this value the more oxygen is consumed, higher peak oxygen uptake values are expected for able-bodied participants compared to their paraplegic counterparts. However, it should be borne in mind that there were no significant differences in the peak values for power output, oxygen uptake and ventilation between able-bodied women and their paraplegic counterparts. Generally speaking, this might be attributed to the cultural factor as women in the Arab countries are less physically active compared to men irrespective of group (i.e., able-bodied or paraplegic).

10.2 The relationships between the RPE and physical and physiological variables

Arm cranking vs. leg cycling

There were very strong linear relationships between the RPE and oxygen uptake, heart rate, ventilation and power output during arm cranking and leg cycling, regardless of gender (all $R^2 \geq 0.87$). Slightly stronger relationships between the RPE and heart rate and between power output and heart rate were observed during leg cycling compared to arm cranking. However, it should be borne in mind that these differences may be considered to be of negligible importance as the overall relationships between the RPE and physical and physiological markers are very strong for both exercise modes.

Effects of gender

With regard to the able-bodied, men and women, very strong linear relationships between the RPE and oxygen uptake, heart rate, ventilation and power output (all $R^2 \geq 0.87$) regardless of exercise mode (i.e., arm cranking and leg cycling) were observed. For the paraplegic individuals, very strong linear relationships between the RPE and physical and physiological markers of exercise intensity (all $R^2 \geq 0.87$) were also observed. This may be attributed to the fact that different increments were used for men and women, regardless of group or exercise mode, which may in turn help the participants to exercise at equal exercise intensities until volitional exhaustion. This seems true especially when considering that all the differences in the rate of change of the RPE, when regressed against absolute power output (PO) between arm cranking and leg cycling and between men and women, regardless of group, diminished when the RPE was regressed against proportion of power output (%PO).

Able-bodied vs. paraplegic

Using *estimation* procedures, a passive process in which an individual indicates how 'hard' or 'easy' an exercise feels, there were very strong linear relationships between the RPE and oxygen uptake, heart rate, ventilation and power output during arm cranking for both able-bodied and paraplegic individuals, regardless of gender (all $R^2 \geq 0.87$). There were also no significant differences in the relationships between RPE

and power output, RPE and heart rate, and RPE and ventilation between able-bodied and paraplegic persons. However, a stronger relationship between the RPE: $\dot{V}O_2$ and between PO: $\dot{V}O_2$ was observed in the able-bodied participants. The stronger relationship between RPE: $\dot{V}O_2$ may be attributed to the fact that paraplegic participants may have been more familiar with arm exercise, which may in turn have led them to underestimate their RPE at a given work rate especially at lower work rates. The strong linear relationship between the RPE and $\dot{V}O_2$ during arm cranking exercise was also evident during *production* procedure ($R^2 \geq 0.96$, chapter 7), an active process in which an individual is asked to produce an exercise intensity equal to a prescribed, given RPE, regardless of group (i.e., able-bodied and paraplegic).

These findings support the utility of the RPE to regulate exercise intensity in individuals with paraplegia with lesions resulting from poliomyelitis infection or SCI. However, it should be born in mind that these individuals were physically active with some who competed at national level. Therefore, the results can be applied to those who are physically active but not sedentary. Another point which should also be considered when use the RPE to complement heart rate to regulate exercise intensity, is that at a given heart rate, the RPE is likely to be 1 to 2 units higher compared to leg cycling and running on treadmill. The higher RPE values at a given heart rate may be attributed to two factors: 1) the smaller muscle activated during arm exercise which means more work per unit of contracting muscle mass. This will in turn increase blood flow and blood lactate concentration. 2) Arm exercise elicits lower peak heart rate values. This means that at a given heart rate, the arms are exercising at higher %HRpeak compared to leg cycling or running on a treadmill.

10.3 Prediction of peak oxygen uptake from sub-maximal RPE

Prediction of peak oxygen uptake from a ramp exercise test

For the able-bodied participants, there were no significant differences between measured and predicted peak oxygen uptake from the three RPE ranges (i.e., 9-13, 9-15 and 9-17) when extrapolated to RPE20. However, for the paraplegic individuals, the predicted $\dot{V}O_2$ peak from RPEs prior to and including RPE13 was significantly higher than the measured $\dot{V}O_2$ peak. The more accurate prediction of $\dot{V}O_2$ peak for able-bodied compared to paraplegic individuals was also confirmed with respect to the smaller LoA and the higher ICC for the three RPE ranges. For both groups, the higher RPE range (i.e., RPEs up to and including RPE17) provided more accurate predictions of $\dot{V}O_2$ peak compared to the lower range (i.e., RPEs up to and including RPE13).

Prediction of peak oxygen uptake from a graded exercise test and a ramp exercise test

For paraplegic individuals, there was no significant difference between measured and predicted $\dot{V}O_2$ peak from the three sub-maximal RPE ranges (i.e., 9-13, 9-15 and 9-17) when extrapolated to RPE20 during the GXT. However, the predicted $\dot{V}O_2$ peak from RPEs prior to and including RPE15 was significantly higher than the measured $\dot{V}O_2$ peak during the ramp exercise test. The high RPE range (i.e., RPEs up to and including RPE17) provided more accurate predictions of $\dot{V}O_2$ peak compared to the low RPE range (i.e., RPEs up to and including RPE13), as reflected by the smaller LoA and the higher ICC during both exercise tests. The GXT provided a more accurate prediction of $\dot{V}O_2$ peak compared to the ramp exercise test, which was also reflected by the narrower LoA and the absence of significant difference between measured and predicted $\dot{V}O_2$ peak from RPEs up to and including RPE15. We speculated that this may be attributed to the fact that more time was spent at each stage, which may in turn have facilitated a more accurate estimation of the RPE.

For the able-bodied participants, there was no significant difference between measured and predicted $\dot{V}O_2$ peak from RPEs prior to and including RPE15 and

RPE17 during the ramp exercise test. However, predicted $\dot{V}O_2$ peak from RPEs prior to and including RPE13, RPE15 and RPE17 was significantly lower than measured $\dot{V}O_2$ peak during the graded exercise test. Therefore, for able-bodied participants the ramp exercise test provided a more accurate prediction of $\dot{V}O_2$ peak compared to the GXT. Lambrick et al. (2009) indicated that the accurate prediction of $\dot{V}O_2$ peak during leg cycling in healthy able-bodied women may be attributed to the more frequent increase in work rate during the ramp exercise test which may in turn have facilitated a more accurate appraisal of the RPE.

Prediction of peak oxygen uptake from a perceptually-guided, graded exercise test

For paraplegic persons, the sub-maximal perceptually-guided, graded exercise test provided quite an accurate prediction of peak oxygen uptake from the three sub-maximal RPE ranges (i.e., 9-13, 9-15 and 9-17) when extrapolated to RPE20. This was especially so after a full familiarization trial, as reflected by the absence of significant differences between measured and predicted values, very strong intraclass correlation coefficients ($ICC \geq 0.92$) and relatively small limits of agreement (i.e., $\pm 6 \text{ ml.kg}^{-1}.\text{min}^{-1}$ (the potential error is 20%)) between measured and predicted values. However, for able-bodied participants the perceptually-guided, graded exercise test did not provide an accurate prediction of peak oxygen uptake from the three sub-maximal RPE ranges (i.e., 9-13, 9-15 and 9-17) when extrapolated to RPE20. This was reflected by the significantly lower predicted values and the wide limits of agreement between measured and predicted $\dot{V}O_2$ peak values. This may indicate that able-bodied individuals are not as familiar with arm exercise as those with paraplegia.

Prediction of peak oxygen uptake from power output

The ACSM equation (i.e., $\dot{V}O_2 \text{ ml.kg}^{-1}.\text{min}^{-1} = 3 \times \text{work rate (kg.m.min}^{-1})/\text{body mass (kg)} + 3.5 \text{ ml.kg}^{-1}.\text{min}^{-1}$, ACSM, 2006), provided quite an accurate prediction of peak oxygen uptake from P O_{peak} for both able-bodied (the potential error is 21%) and paraplegic individuals (the potential error is 19%). This was reflected by the finding of no significant difference between measured and predicted $\dot{V}O_2$ peak values, very

strong ICC between measured and predicted $\dot{V}O_2$ peak values (ICC = 0.94) and relatively narrow LoA between measured and predicted $\dot{V}O_2$ peak values (i.e., $1 \pm 5 \text{ ml.kg}^{-1}.\text{min}^{-1}$). These findings have important implications for estimating $\dot{V}O_2$ peak for large groups of people during arm cranking exercise, especially when considering that the direct measurement of $\dot{V}O_2$ peak is expensive.

Prediction of peak power output from a perceptually-guided, graded exercise test

In study 5a, we have assessed the accuracy of predicting $\dot{V}O_2$ peak from POpeak using the ACSM equation (ACSM, 2006). Therefore, we were interested in assessing the accuracy of predicting POpeak, and consequently $\dot{V}O_2$ peak, from a perceptually-guided, graded exercise test in another independent group of able-bodied individuals (study 5b). The results showed that predicted POpeak from the three sub-maximal RPE ranges (i.e., 9-13, 9-15 and 9-17) when extrapolated to RPE20, were significantly lower than measured POpeak. These findings substantiate the finding that able-bodied participants are less familiar with arm cranking exercise compared to those with paraplegia. This seems true as the predicted POpeak values were lower compared to the measured POpeak values.

In summary, using the production mode of the RPE, $\dot{V}O_2$ peak may be predicted from sub-maximal $\dot{V}O_2$ values elicited during the three sub-maximal RPE ranges (i.e., 9-13, 9-15 and 9-17) during the second perceptually-guided, graded exercise for paraplegic individuals, but not for able-bodied participants. The potential error in a worst case scenario for the three RPE ranges for the paraplegic persons was 19%. Using the estimation mode of the RPE, the ramp exercise test is not recommended to predict $\dot{V}O_2$ peak for paraplegic individuals due to the large potential error involved. Alternatively, the GXT could be used to predict $\dot{V}O_2$ peak with these individuals. However, for the able-bodied participants the ramp exercise not the GXT should be used to predict $\dot{V}O_2$ peak. Finally, $\dot{V}O_2$ peak could be predicted from POpeak using the ACSM equation (ACSM, 2006). The potential error involved was 20% for both groups.

The prediction of $\dot{V}O_2$ peak from a sub-maximal perceptually-guided, graded exercise test has the advantage of improving exercise adherence as participants have control of the exercise intensity. This is of importance especially with regard to the consideration that depression symptoms are prevalent among paraplegic individuals.

The prediction of $\dot{V}O_2$ peak from sub-maximal RPE values elicited during the GXT (for paraplegic individuals) and the ramp exercise test (for able-bodied participants) has the advantage of eliminating the negative affect which is associated with high intensity exercise (> RPE 17). Finally, due to the high cost of the direct measurement of $\dot{V}O_2$ peak, the prediction of $\dot{V}O_2$ peak from POpeak using the ACSM equation may be a more economical means of assessment in a clinical environment. It would also facilitate the estimation of $\dot{V}O_2$ peak in large groups of people.

When using the *estimation* procedure, participants usually report a higher peripheral RPE at a given work rate and at the termination of the exercise test compared to overall RPE. For these reasons, emphasis should be placed on the 'peripheral' rather than the 'overall' RPE, to predict $\dot{V}O_2$ peak, particularly as use of the overall RPE has been shown to lead to over estimation values of $\dot{V}O_2$ peak. However, when the RPE is used to actively regulate the exercise intensity (*production*), such as when it is used in perceptually-guided, graded exercise testing, it is recommended that the overall RPE should be used as use of the peripheral RPE may lead to under estimation of $\dot{V}O_2$ peak due to the smaller muscle mass activated during arm cranking exercise.

10.4 The scalar property of the RPE during arm cranking exercise

Previous research has indicated that the rating of perceived exertion scales with time to volitional exhaustion whilst exercising at constant sub-maximal work rate (Horstman et al., 1979; Noakes, 2004, 2008; Eston et al., 2007; Crewe et al., 2008; Faulkner et al., 2008; Joseph et al., 2008). In other words, differences in the rate of change in the RPE when regressed against absolute time between exercises of different durations disappear when the RPE is regressed against the proportion of time

completed or the time remaining to the end of the exercise task. Therefore, the aim of the sixth study was to assess the scalar property of the RPE during arm cranking exercise in able-bodied and paraplegic individuals.

We observed strong linear relationships between the RPE and time to volitional exhaustion during the constant-load exercise test at 50% Δ ($R^2 \geq 0.88$) and 70% Δ ($R^2 \geq 0.92$) for able-bodied and paraplegic individuals. This finding was in accordance with previous observations during running and cycling in able-bodied individuals (Horstman et al., 1979; Crewe et al., 2008). Although the RPE increased at an expectedly greater rate of change during the constant-load exercise test at 70% Δ compared to 50% Δ when the RPE was regressed against time; these differences disappeared when the RPE was regressed against the proportion of time elapsed. This observation is in accordance with previous research during running and cycling in able-bodied individuals (Horstman et al., 1979; Noakes, 2004; Eston et al., 2007; Crewe et al., 2008; Faulkner et al., 2008; Joseph et al., 2008).

As such, these findings confirm that the RPE scales with time while exercising at a constant work rate during arm cranking exercise in healthy able-bodied and paraplegic participants. This may indicate that the RPE is set at the beginning of the exercise and increases as a proportion of time completed or remaining regardless of the size of the muscle mass activated during exercise. These findings have important implications as they indicate that the RPE may be used to predict time to exhaustion while exercising at sub-maximal constant work rate. For example, if the exercise instructor observes that one of the participants in his/her class reporting an RPE of 17 in the first 5 minutes; the work rate should be decreased to allow this person to finish the entire duration of the exercise (e.g., 30 minutes).

10.5 Proportion of peak oxygen uptake at a given RPE

Paraplegic participants exercised at a significantly higher proportion of peak oxygen uptake at RPE of 13, 15 and 17 during the graded exercise test and the ramp exercise test compared to their able-bodied counterparts (study 3). Similar findings were observed at RPEs of 9, 11, 13, 15 and 17 during the first and the second

perceptually-guided, graded exercise test (study 4). The lower proportions of peak oxygen uptake at a given RPE for able-bodied participants confirm their lower familiarity with arm exercise. These findings have also helped in interpreting the lower predicted peak oxygen uptake values for able-bodied participants during the ramp exercise test (study 3), the GXT (study 3) and the two perceptually-guided, graded exercise tests (study 4 and study 5b).

10.6 Overall vs. peripheral RPE

Able-bodied and paraplegic individuals reported higher peripheral RPE values at the termination of the ramp exercise test and the graded exercise test (study 3 and study 6). Similarly, participants, regardless of group (i.e., able-bodied and paraplegic), reported a higher peripheral RPE compared to overall RPE at 2 minutes into the exercise and at the termination of the constant-load exercise tests at 50% Δ and 70% Δ (study 6). To our knowledge, these are the first studies which have assessed peripheral RPE versus overall RPE during maximal and sub-maximal arm cranking exercise in paraplegic individuals. These findings are in agreement with Goosey-Tolfrey and Kirk, (2003) and Lenton et al. (2008) during wheelchair propulsion exercise in able-bodied and paraplegic individuals. The higher peripheral RPE may be attributed to the smaller muscle mass activated during arm cranking exercise (Borg et al., 1987; McArdle et al., 2007). This may reflect the higher work rate per unit of contracting muscle mass (Åstrand et al., 2003), which will increase blood flow and blood lactate in the arms (Borg et al., 1987) and which in turn causes higher peripheral fatigue (RPE). In addition, arm exercise elicits lower peak heart rate and ventilation values compared to leg cycling (Franklin et al., 1983, Vander et al., 1984; Aminoff et al., 1996) or walking/running on treadmill. These observations are in accordance with the findings of Ekblom and Goldbarg (1971), who indicated that peripheral perceived exertion is dominant during exercise involving smaller muscle groups; whereas, central perceived exertion is dominant during exercise involving large muscle groups.

10.6 The importance of using limits of agreement

Limits of agreement are important tool to assess the agreement between a new method to measure a given variable against an established one (Bland and Altman, 1986). These studies demonstrate the importance of using LoA to assess the accuracy of predicted $\dot{V}O_2$ peak from the three sub-maximal RPE ranges (i.e., 9-13, 9-15 and 9-17) versus measured $\dot{V}O_2$ peak during both *estimation* and *production* procedures. For example, in study 3, there was no significant difference between measured and predicted peak oxygen uptake from the three RPE ranges during the GXT for paraplegic individuals. However, LoA did reveal that there was a margin error of -1 ± 11 , 0 ± 6 and $0 \pm 4 \text{ ml.kg}^{-1}.\text{min}^{-1}$ between measured and predicted $\dot{V}O_2$ peak values from the three RPE ranges, respectively. Similarly, there was no significant difference between measured and predicted $\dot{V}O_2$ peak values from the three sub-maximal RPE ranges for paraplegic individuals from the second trial of the perceptually-guided, graded exercise test (Study 4). However, LoA did show a margin error of $\sim 0 \pm 6 \text{ ml.kg}^{-1}.\text{min}^{-1}$ from the three RPE ranges.

10.7 The thesis has added

- The findings from the thesis confirmed that arm exercise elicits lower peak values for oxygen uptake, power output, ventilation and heart rate compared to leg cycling.
- The findings confirmed the strong linear relationship between the RPE and power output, heart rate, ventilation and oxygen uptake during arm cranking exercise in able-bodied and paraplegic persons and during leg cycling.
- The thesis showed for the first time that $\dot{V}O_2$ peak can be predicted from sub-maximal $\dot{V}O_2$ values elicited during the second perceptually-guided, graded exercise test when extrapolated to RPE20 for paraplegic individuals but not for able-bodied individuals.

- It showed that for paraplegic persons the GXT provided more accurate prediction of $\dot{V}O_2\text{peak}$ compared to the ramp exercise test.
- The results showed that for able-bodied participants the ramp exercise test provided more accurate prediction of $\dot{V}O_2\text{peak}$ compared to the GXT.
- The results showed very strong linear relationship between the RPE and time to volitional exhaustion whilst exercising at constant-load exercise intensities during arm cranking exercise in able-bodied and paraplegic persons.
- The results showed for the first time that the RPE scales with time during arm cranking exercise in able-bodied and paraplegic individuals. In other words, similar proportions of time were observed at a given RPE while exercising at two different constant-load exercise intensities during arm cranking.

Chapter eleven

Conclusion, limitations and recommendations for future research

11.1 Conclusion

The rating of perceived exertion has a very strong linear relationship with oxygen uptake, heart rate, ventilation and power output during arm cranking and leg cycling in able-bodied participants ($R^2 \geq 0.87$), regardless of gender, and during arm cranking in able-bodied and paraplegic persons ($R^2 \geq 0.87$). However, a slightly stronger relationship was observed between the RPE and heart rate and between PO and heart rate during leg cycling compared to arm cranking. A stronger relationship between RPE and $\dot{V}O_2$ and between power output and $\dot{V}O_2$ was also observed for able-bodied participants, regardless of gender, compared to their paraplegic counterparts.

For paraplegic persons, peak oxygen uptake may be predicted with reasonable accuracy from sub-maximal RPE values elicited during a graded exercise test when extrapolated to RPE20. Similarly, peak oxygen uptake may be predicted with reasonable accuracy from sub-maximal oxygen uptake values elicited during a perceptually-guided, graded exercise test when these values extrapolated to RPE20. For able-bodied participants, the ramp exercise test provided more accurate prediction of peak oxygen uptake compared to the graded exercise test. The sub-maximal perceptually-guided, graded exercise test provided significantly lower estimation of peak oxygen uptake for able-bodied participants.

Finally, there was no significant difference in the rate of change of the RPE when expressed against the proportion of time to volitional exhaustion while exercising at two different constant-load exercise intensities during arm cranking exercise in healthy able-bodied and paraplegic participants. This has important implications for using the RPE as a sensitive predictor of time to exhaustion while exercising at sub-maximal constant-load during arm cranking exercise for both groups.

11.2 Limitations and Recommendations for future research

The findings from the six studies in this thesis should be interpreted within the following limitations, which may have influenced the findings.

1. Upper body strength was not measured for able-bodied and paraplegic individuals. Measurement of upper body strength may have helped in interpreting some of the differences in the physiological and physical responses between the two groups (i.e., able-bodied and paraplegic). Therefore, future research should consider measuring upper body strength, especially if direct comparisons between able-bodied and paraplegic are desired.
2. The accuracy of predicting $\dot{V}O_2$ peak from sub-maximal $\dot{V}O_2$ values elicited during sub-maximal exercise tests was assessed in physically active, but not arm-trained, able-bodied participants. Therefore, it would be of interest to assess the validity of predicting peak oxygen uptake from sub-maximal $\dot{V}O_2$ values during arm cranking exercise in arm-trained, able-bodied individuals (i.e., swimmers, kayakers and rowers).
3. The size of the samples used in the various studies may be considered to be relatively small, although the numbers of participants used in the studies are generally in accordance with previous research in these areas.
4. The prediction of $\dot{V}O_2$ peak from the rating of perceived exertion was assessed in paraplegic individuals, who were characterized with spinal cord injury at or below the sixth thoracic vertebra or poliomyelitis infection, using *estimation* and *production* procedures. These individuals have normal heart rate. It would therefore be of relevance and interest to assess the validity of predicting $\dot{V}O_2$ peak from sub-maximal RPE values in paraplegic individuals with complete spinal cord injury above the sixth thoracic vertebra, as these individuals have an attenuated heart rate response to exercise as a result of the disruption of sympathetic signals to the heart.
5. We have assessed the accuracy of predicting peak oxygen from a perceptually-guided, graded exercise test using 3-minute stages. Therefore, it would be of interest to assess the validity of predicting peak oxygen uptake from a perceptually-guided, graded exercise test of

different duration at each RPE level (e.g., 2-minute vs. 3-minute or 2-minute vs. 4-minute) in arm-trained, able-bodied and paraplegic individuals. This is of importance as previous research (Eston et al., 2006) showed more accurate predictions of peak oxygen uptake from 2-minute stages compared to 4-minute stages during leg cycling in able-bodied participants.

6. Delta concept ' Δ ' (i.e., the difference between the gas exchange threshold and peak power output) is a suitable method to standardise the work rate between participants. Therefore, it is of interest to assess the validity of the ' Δ ' to regulate exercise intensity during arm cranking exercise in arm-trained able-bodied and paraplegic individuals who differ in fitness level.

7. We have not used a verification to ensure true $\dot{V}O_2$ peak values. Therefore, future research should consider including a verification to ensure true $\dot{V}O_2$ peak values (e.g., exercising at 105% of P_Opeak until exhaustion).

8. We have employed 50 rpm and 60 rpm during all the thesis studies. Future research should consider employing higher rpm (e.g., 70 rpm). Price and Campbell, (1997) observed higher $\dot{V}O_2$ peak when 70 rpm was employed compared to 60 rpm.

9. For paraplegic individuals, an RPE of 13 corresponds to $\geq 50\%$ $\dot{V}O_2$ peak during both *estimation* and *production* protocols. Therefore, it would be worth assessing the efficacy of arm training programmes using RPE of 13 on improving peak functional capacity in paraplegic individual. This is of great importance as participants have full control of the exercise intensity which may in turn improve exercise adherence.

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Appendices

- Appendices A1, A2, A3, A4 and A5 are copies of the five published papers as they appear in print.

- Appendices 2A, 2B, 2C, 2D and 2E are copies of the information sheets for able-bodied and paraplegic participants.

- Appendices 3A, 3B, 3C, 3D and 3E are copies of the informed consent for able-bodied and paraplegic participants.

- Appendix 4 is the table which used to transform correlation coefficients (r) to Fisher Z_r values to approximate for normality distribution

ORIGINAL ARTICLE

Relationship Between Perceived Exertion and Physiologic Markers During Arm Exercise With Able-Bodied Participants and Participants With Poliomyelitis

Harran Q. Al-Rahamneh, MPE, James A. Faulkner, PhD, Christopher Byrne, PhD, Roger G. Eston, DPE

ABSTRACT. Al-Rahamneh HQ, Faulkner JA, Byrne C, Eston RG. Relationship between perceived exertion and physiologic markers during arm exercise with able-bodied participants and participants with poliomyelitis. *Arch Phys Med Rehabil* 2010;91:273-7.

Objective: To investigate the strength of the relationship between ratings of perceived exertion (RPE) and oxygen uptake ($\dot{V}O_2$), heart rate, ventilation ($\dot{V}E$) and power output (PO) during an arm-crank ramped exercise test to volitional exhaustion in men and women who differed in physical status.

Design: Each participant completed an arm-crank ramp exercise test to volitional exhaustion. PO was increased by $15W \cdot min^{-1}$ and $6W \cdot min^{-1}$ for men and women able-bodied participants, respectively; for the poliomyelitis participants, $9W \cdot min^{-1}$ and $6W \cdot min^{-1}$ increments were used for men and women, respectively.

Setting: Laboratory facilities at a university.

Participants: Able-bodied participants ($n=16$; 9 men, 7 women) and participants with poliomyelitis ($n=15$, 8 men, 7 women) volunteered for the study.

Main Outcome Measures: Strength of the relationship (R^2 values) between RPE and $\dot{V}O_2$, heart rate, $\dot{V}E$ and PO.

Results: There were significantly higher values for maximum $\dot{V}O_2$ and maximum PO for able-bodied men compared with their counterparts with poliomyelitis ($P<.05$). However, when the data were controlled for age, there were no significant differences in these values ($P>.05$). Similar results were observed for the women who were able-bodied as well as for the women who had poliomyelitis ($P>.05$). The relationships between heart rate and RPE and $\dot{V}E$ and RPE for able-bodied patients and patients with poliomyelitis were similar ($R^2>.87$). The relationship between $\dot{V}O_2$ and RPE was stronger in the able-bodied participants compared with the participants with poliomyelitis, regardless of sex ($P<.05$). However, when the data were controlled for age, there was no significant difference in the strength of this relationship between able-bodied participants and those with poliomyelitis, regardless of sex ($P>.05$).

Conclusions: RPE is strongly related to physiologic markers of exercise intensity during arm exercise, irrespective of sex or participant's poliomyelitis status.

Key Words: Poliomyelitis; Rehabilitation.

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POLOIOMYELITIS IS A SEVERE viral infection of the central nervous system. Survivors of poliomyelitis have an impaired autonomic and motor nervous system,^{1,2} often associated with the lower limbs, as motor neurons located in the front part of the spinal cord are attacked.³ The muscle atrophy and weakness typically observed in persons with chronic poliomyelitis affects biomechanical,⁴ postural,⁵ and pulmonary function.⁶ Previous research has reported that persons with poliomyelitis elicit lower maximal values for $\dot{V}O_2$, PO, and $\dot{V}E$ compared with able-bodied participants.^{7,8} Accordingly, aerobic exercise is an effective strategy used to maintain or improve cardiovascular endurance for these persons.^{9,10}

The perception of cardiorespiratory, metabolic, and musculoskeletal mediators of exertion plays an important role in the regulation of exercise intensity and compliance to exercise.^{11,12} The Borg 6–20 RPE Scale is widely used to assess sensations of exertion in relation to heart rate, $\dot{V}O_2$, $\dot{V}E$, and PO.¹¹ It has been consistently demonstrated that RPE is a reliable and valid tool to evaluate whole-body exertion with able-bodied men and women of high and low fitness during cycle ergometry and treadmill exercise.^{13–15} The findings with regard to the utility of RPE with patients with either spinal cord injury or spinal cord disease are equivocal. Some research has indicated that the RPE is a useful and reliable tool to control and regulate exercise intensity.^{16–18} Conversely, some studies have reported that it is an inappropriate measure in such populations.^{19,20}

Although research has shown that the RPE may correlate poorly with exercise performance in persons with postpoliomyelitis,^{21,22} recent evidence suggests that the RPE is effective in controlling moderate (~50% $\dot{V}O_{2\text{peak}}$) and vigorous (~70% $\dot{V}O_{2\text{peak}}$) intensities during hand cycling exercise in persons with spinal cord injury.¹⁷ This has been shown despite such persons often exhibiting abnormal heart rate, hemodynamic (ie, blood distribution), and metabolic responses during exercise, most likely because of a loss of sympathetic innervation.^{18,23,24}

List of Abbreviations

ANCOVA	analysis of covariance
ANOVA	analysis of variance
PO	power output
POmax	maximum power output
RER	respiratory exchange ratio
RPE	rating of perceived exertion
$\dot{V}E$	ventilation
$\dot{V}E_{\text{max}}$	maximum expired volume
$\dot{V}O_2$	oxygen uptake
$\dot{V}O_{2\text{max}}$	maximum oxygen consumption
$\dot{V}O_{2\text{peak}}$	peak oxygen consumption

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Accordingly, the prescription, regulation, and monitoring of exercise using heart rate may not be an appropriate method because of the attenuated heart rate and cardiovascular response that may develop from an impaired autonomic and motor nervous system.^{3,18}

The purpose of this study was to examine the utility of the RPE to assess exercise intensity during continuous incremental arm-crank exercise in patients with poliomyelitis. Specifically, we were interested in assessing the strength of the relationship between RPE and heart rate, $\dot{V}O_2$, $\dot{V}E$, and PO during arm exercise and whether the relationships were moderated by able-bodied participant status and sex. Based on findings by Goosey-Tolfrey et al.,¹⁷ we hypothesized that strong relationships would be evident between the RPE and each marker of exercise intensity and that the relationships would not be moderated by the status or sex of the participants.

METHODS

Participants

In accordance with an alpha less than .05 (2-tailed) and 80% power, it was determined that a meaningful effect size would be obtained from a sample of greater than 30 participants.²⁵ Therefore, 16 men and women of able-bodied status and 15 men and women with poliomyelitis volunteered to take part in the study. Participants with poliomyelitis had flaccid paralysis of the lower limbs. The inclusion criteria were provision of written informed consent, less than 45 years of age, no prior experience of arm-crank exercise or perceptual scaling (Borg 6–20 RPE scale), and no cardiovascular or cardiorespiratory complications. All participants had their blood pressure measured^a prior to exercise participation. The study was conducted in agreement with institutional ethics at the Faculty of Physical Education at the University of Jordan.

Procedures

Each participant performed an arm cranking ramp exercise test designed to establish maximal functional capacity on a Lode arm ergometer.^b The resistance on the ergometer was manipulated using the Lode Workload Programmer, accurate to $\pm 1W$, which was independent of pedal cadence. Participants maintained a cadence of 50 rev·min⁻¹ throughout the exercise tests.²⁶

Online respiratory gas analysis occurred throughout each exercise test via a breath-by-breath automatic gas calibrator system.^c Expired air was collected continuously using a face mask to allow participants to verbally communicate to the experimenter (ie, when reporting RPE). The system was calibrated (gas, pressure) prior to each exercise test in accordance with manufacturer's guidelines. A wireless chest strap telemetry system^d continuously recorded heart rate during each exercise test. All physiologic (heart rate, $\dot{V}O_2$, $\dot{V}E$, RER), and physical (PO, time) outputs were concealed from the participant during the exercise tests. Participants were familiarized with the Borg 6–20 RPE scale and were given standardized instructions on how to report their overall feelings of exertion prior to the test.¹¹ Any questions concerning the scale were answered before exercise commenced.

Arm-Crank Ramp Exercise Test

Pilot research was used to identify an increment in PO that would enable $\dot{V}O_{2\text{max}}$ to be ascertained within approximately 8 to 12 minutes during arm-crank exercise, as recommended by the American College of Sports Medicine.²⁷ After a 4-minute warmup at 0W, the work rate increased by 15W·min⁻¹ and

6W·min⁻¹ for able-bodied men and women, respectively. For the participants with poliomyelitis, 9W·min⁻¹ and 6W·min⁻¹ increments for men and women, respectively, were considered to be more appropriate. During the last 20 seconds of each minute and at the completion of the exercise test, participants estimated their overall RPE. The termination of the exercise test was determined by a plateau in oxygen consumption, failure to maintain the required cadence, or volitional cessation of the exercise test at exhaustion. A postexercise blood lactate concentration 8m-mol⁻¹ or greater confirmed that participants achieved their maximal functional capacity.²⁸

Data Analysis

Descriptive statistics. A series of independent-sample *t* tests were used to investigate whether sex and participants' status moderated the maximal physiologic ($\dot{V}O_2$, heart rate, $\dot{V}E$, RER, lactate), perceptual (RPE), and physical (PO) parameters observed at the termination of the exercise test. Because the men and women with poliomyelitis were significantly older than their able-bodied counterparts, where there were significant differences, ANCOVA (with age as the covariate) was used to compare the data.

RPE and physiologic/physical markers of exercise intensity. The RPEs recorded during the final 20 seconds of each minute and at the termination of the arm-crank exercise test were regressed against the corresponding mean $\dot{V}O_2$, heart rate, $\dot{V}E$, and PO in a linear regression analysis for each participant. Individual R^2 values were obtained for each participant to identify the relationship between the RPE and each physiologic marker of exercise intensity. All R^2 values calculated via the linear regression analyses were converted to Fisher Zr values to approximate for the normality of the sampling distribution. This was deemed appropriate because research has shown that the sampling distribution of correlation coefficients may not be normally distributed.²⁹ A 3-factor ANOVA, Zr values of the bivariate combinations \times participants' status \times sex, was used to compare the strength of the relationships between $\dot{V}O_2$ and RPE, heart rate and RPE, $\dot{V}E$ and RPE, and PO and RPE and whether sex or participants' status moderated these relationships. If data violated assumptions of sphericity using the Mauchley test, the Greenhouse Geisser epsilon correction factor was applied to improve the validity of the F-ratio. Alpha was set at .05. Post hoc analysis using dependent or independent *t* tests were performed where appropriate, to identify any significant differences in the strength of the relationships.

Comparison of the b coefficient slopes of RPE against PO. For each individual, the RPE values were regressed against PO and as a proportion of the maximal PO, using RPE as the dependent variable (y axis) and PO (x axis) as the independent variable. Independent-sample *t* tests were used to assess whether the rate of change in the RPE (*b* coefficients) was moderated by the participants' status or sex when expressed with absolute PO or as a proportion of maximal PO. Data were analyzed using SPSS for Windows, version 15.^e

RESULTS

Descriptive Statistics

Participant descriptives can be observed in table 1. Men and women with poliomyelitis were significantly older than their able-bodied counterparts ($t_{7,21} = -10.58$, $P < .01$) and ($t_{6,37} = -7.44$, $P < .01$), respectively. Although there was no significant difference in body mass between able-bodied participants and those with poliomyelitis, regardless of sex ($P > .05$), able-bodied men and women were significantly taller than their

Table 1: Demographic Information for Participants

Descriptive Statistics	Able-Bodied Men (n=9)	Men With Poliomyelitis (n=8)	Able-Bodied Women (n=7)	Women With Poliomyelitis (n=7)
Age (y)	20.3±0.5	35.0±4.0*	20.8±0.8	33.4±5.0†
Height (cm)	176.2±6.0	168.0±10.1*	162.0±6.4	147.4±5.0†
Weight (kg)	70.4±17.1	71.0±16.2	56.4±7.6	55.1±12.0

NOTE. Values are mean ± SD.

*Significant difference between able-bodied men and men with poliomyelitis ($P<.05$).†Significant difference between able-bodied women and women with poliomyelitis ($P<.05$).

counterparts who had poliomyelitis ($t_{15}=2.14$, $P<.05$) and ($t_{12}=4.76$, $P<.01$), respectively. Descriptive statistics (mean ± SD) reported at the termination of the exercise tests can be observed in table 2. Independent-sample *t* tests demonstrated no significant differences in the maximum heart rate, RER, $\dot{V}E$ max, lactate, and maximum RPE between able-bodied men and their counterparts with poliomyelitis at the termination of the exercise tests ($P>.05$). Although significantly higher values for POmax ($t_{15}=2.47$, $P<.05$) and $\dot{V}O_2$ max ($t_{15}=2.21$, $P<.05$) were observed for able-bodied men, when the data were corrected for age (covariate) using ANCOVA, there were no significant differences in these 2 variables ($P>.05$). Further independent-sample *t* tests revealed no significant differences between able-bodied women and those with poliomyelitis for all the physiologic and physical variables (all $P>.05$). Further analysis revealed significantly higher values for $\dot{V}O_2$ max ($t_{29}=4.71$, $P<.001$), $\dot{V}E$ max ($t_{29}=548$, $P<.001$) and POmax ($F_{29}=8.51$, $P<.001$) for men compared with women at the completion of the exercise test, regardless of participants' status.

RPE and Physiologic/Physical Markers of Exercise Intensity

Linear regression analyses of individual $\dot{V}O_2$ and RPE, heart rate and RPE, $\dot{V}E$ and RPE, and PO and RPE produced average R^2 values of $R^2=.86$ to $R^2=.96$ when (re)converting Fisher Z_r scores to R^2 values (table 3). A 3-factor ANOVA revealed a significant difference in the strength of these relationships ($F_{3,81}=6.28$, $P<.05$). Paired sample *t* tests using a Bonferroni adjustment demonstrated that the PO and RPE relationship was significantly stronger than $\dot{V}O_2$ and RPE or $\dot{V}E$ and RPE ($P<.001$). The ANOVA revealed that sex did not moderate any of the relationships between RPE and $\dot{V}O_2$, heart rate, $\dot{V}E$ and PO ($F_{3,81}=.29$, $P>.05$). However, participants' status did moderate these relationships ($F_{3,81}=3.18$, $P<.05$). A series of independent sample *t* tests using a Bonferroni adjustment demonstrated a significantly stronger relationship between $\dot{V}O_2$ and RPE for able-bodied participants than those with poliomyelitis

Table 3: Mean R^2 Values for the Relationships Between the RPE and Physiologic and Physical Markers When (Re)converting Fisher Z_r Scores to R^2 Values During Arm-Crank Exercise for Able-Bodied Participants and Participants With Poliomyelitis (Men and Women)

Group	$\dot{V}O_2$:RPE	HR:RPE	$\dot{V}E$:RPE	PO:RPE
Able-bodied men	.94	.90	.87	.95
Able-bodied women	.93	.95	.90	.96
Men with poliomyelitis	.87	.93	.90	.94
Women with poliomyelitis	.87	.93	.92	.95

Abbreviation: HR, heart rate.

($t_{21}=2.14$, $P<.05$). There were no differences in all other relationships between the 2 groups. However, when controlling for age (covariate) using ANCOVA, the significant difference in the strength of the relationship between $\dot{V}O_2$ and RPE between able-bodied participants and those with poliomyelitis was diminished ($P>.05$).

Comparison of the *b* Coefficient Slopes of RPE Against PO

A comparison of the within-subject slopes (*b* coefficients) revealed that able-bodied participants and those with poliomyelitis had a similar increase in the rate of change in the RPE when expressed against absolute PO ($b=.18\pm.10$, $b=.18\pm.07$, respectively; $t_{29}=.08$, $P>.05$), or as a proportion of maximal PO ($b=.14\pm.03$, $b=.12\pm.03$, respectively; $t_{29}=1.35$, $P>.05$).

Separate independent-samples *t* tests demonstrated a significantly faster rate of change in the RPE when expressed against absolute PO for able-bodied women compared with able-bodied men ($b=.27\pm.02$, $b=.11\pm.09$, respectively; $P<.05$), and for women with poliomyelitis compared with men with poliomyelitis ($b=.22\pm.08$, $b=.15\pm.05$, respectively; $P=.05$). When the rate of change in the RPE was expressed as a proportion of maximal PO, there were no sex differences for both able-bodied participants and participants with poliomyelitis (both $P>.05$).

DISCUSSION

This study assessed the physiologic and perceptual responses of able-bodied participants and participants with poliomyelitis during arm-crank exercise to volitional exhaustion. The results demonstrate strong relationships between the RPE and $\dot{V}O_2$, heart rate, $\dot{V}E$ and PO during an arm-crank exercise, regardless of sex or participants' status. As such, the study provides evidence that persons with poliomyelitis can perceptually rate their level of exertion in relation to measured physiologic responses as accurately as able-bodied participants.

The observed higher values for $\dot{V}O_2$ max and POmax for able-bodied men compared with men who had poliomyelitis

Table 2: Descriptive Statistics Reported at the Termination of the Arm-Crank Test for Able-Bodied Participants and Participants With Poliomyelitis

Group	n	$\dot{V}O_2$ max (mL·kg ⁻¹ min ⁻¹)	HRmax (b·min ⁻¹)	RERmax	$\dot{V}E$ max (L·min ⁻¹)	Lactate (m·mol ⁻¹)	RPEmax	POmax (W)	Time (s)
Able-bodied men	9	28.4±5.0	163±19	1.08±0.07	73±17	8.0±2.0	19.6±0.7	120±13*	472±46
Able-bodied women	7	19.0±2.2	161±17	1.06±0.08	41±5	9.0±2.3	19.6±0.8	54±8	532±85
Men with poliomyelitis	8	24.0±4.0	165±14	1.05±0.05	65±18	8.4±2.0	19.4±1.1	96±27	630±175
Women with poliomyelitis	7	19.0±4.1	155±20	1.01±0.09	43±8	9.0±3.1	18.7±1.1	53±6	526±56

NOTE. Values are mean ± SD. Significant difference between the able-bodied men and men with poliomyelitis ($P<.05$).

Abbreviations: HRmax, maximum heart rate; RERmax, maximum respiratory exchange ratio; RPEmax, maximum rating of perceived exertion.

supports previous research by Nollet et al.⁸ These authors observed a significantly lower PO, $\dot{V}O_2$, and $\dot{V}E$ at the termination of cycle ergometry tests for persons with poliomyelitis than able-bodied participants. As oxygen uptake is directly dependant on the rate of work, it is logical to expect $\dot{V}O_{2\text{max}}$ to be higher in able-bodied men because of the higher POmax. The higher POmax in able-bodied participants may not only be the result of a larger muscle mass, but may also be the result of able-bodied participants using their trunk and leg muscles for stabilization and as a fulcrum from which to push during exercise.²⁴ However, it should be noted that the difference in POmax and $\dot{V}O_{2\text{max}}$ was most likely attributed to the age difference between the 2 groups. When the POmax and $\dot{V}O_{2\text{max}}$ data were corrected for age using ANCOVA, the differences disappeared.

Nevertheless, previous research has demonstrated no differences in POmax and $\dot{V}O_{2\text{max}}$ between persons of varying age during arm exercise.³⁰ Despite differences in POmax and $\dot{V}O_{2\text{max}}$ being evident in the able-bodied men and men with poliomyelitis, the results demonstrated no differences between able-bodied women and women with poliomyelitis across all physiological and physical markers of exercise intensity. This may be considered to be a surprising finding because such persons have impaired blood redistribution, lower peak stroke volume, and lower peak or maximal oxygen uptake.³¹

Although low correlations between PO and RPE have been reported in participants with postpoliomyelitis syndrome,^{21,22} the relationship was particularly strong ($R^2 \geq .94$) in the present study. This may be a consequence of the exercise mode and exercise protocols used. The present study used a ramp protocol, which may have facilitated a continuous anchoring of RPE to increases in exercise intensity. The relationship between $\dot{V}O_2$ and RPE in able-bodied participants was significantly stronger than in participants with poliomyelitis ($R^2 = \sim .94$ cf. $\sim .87$); however, when controlling for age, there was no significant difference ($P > .05$). Although it is unlikely that $\dot{V}O_2$ can be directly associated with the RPE because it cannot be directly sensed during exercise,³² the impaired blood redistribution and reduced oxygen transport capacity of such persons may indirectly contribute to this difference in the relationship between $\dot{V}O_2$ and RPE between the 2 groups.³¹ No differences were observed in the strength of the relationships between heart rate and RPE and $\dot{V}E$ and RPE—2 physiologic mediators of exercise intensity that may be directly (perceptually) monitored by the person during exercise.³²

As the strength of the relationship between $\dot{V}O_2$ and RPE was significantly different before controlling for age between the 2 groups in this study, we assessed whether these differences could be attributed to the different ramp rates in the various groups. However, when the RPE was expressed against absolute PO and also as a proportion of maximal PO, no differences in the rate of change in the RPE were observed. The difference in the relationship between $\dot{V}O_2$ and RPE was therefore not attributable to the varying ramp rates.

As expected, the rate of change in the RPE against absolute PO was greater for able-bodied women participants and women participants with poliomyelitis than their counterpart men. However, when expressed as a proportion of maximal PO, no differences were observed between men and women, providing further evidence that the study design did not influence the perceptual response of participants during the study.

When considering the strong relationships observed between the RPE and physiologic markers of exercise intensity, we feel that the RPE may be a useful tool to assess, monitor, and regulate exercise intensity in persons with poliomyelitis within a clinical assessment environment. We feel that the RPE may

be a useful indicator of exercise performance during submaximal and maximal exercise tests for these patients. Previous research has demonstrated the RPE to be an appropriate method to increase motivation and adherence to exercise participation.³³ This may be considered particularly important with persons with poliomyelitis, because such patients may lack motivation and compliance to exercise participation as a result of clinical depression.³⁴ Parfitt et al³³ demonstrated that during 20 minutes of exercise at either a prescribed (based on 65% $\dot{V}O_{2\text{max}}$) or preferred treadmill intensity, although there were no differences in RPE between conditions, able-bodied participants actually exercised at a higher intensity (71% $\dot{V}O_{2\text{max}}$) in the preferred exercise condition. Accordingly, the RPE may be considered a useful means to promote appropriate aerobic exercise intensities, thus improving the cardiovascular fitness and health of the persons with poliomyelitis.

Study Limitations

Some limitations have been identified with the study. A larger sample size and a more comparative study population, particularly with regard to the age of the able-bodied participants and participants with poliomyelitis, may have enabled a more appropriate evaluation of the utility of the RPE. In hindsight, it would also have been useful to assess the upper body strength of all participants, because this may have helped in the interpretation of some of the physiologic differences observed between able-bodied participants and participants with poliomyelitis. Future research studies that explore the utility of the RPE with persons with poliomyelitis should take these factors into account.

CONCLUSIONS

This study has provided further evidence that RPEs are strongly related to physiologic markers of exercise intensity during arm exercise ($R^2 > .87$), irrespective of sex or participants' status. Accordingly, persons with poliomyelitis can accurately rate their level of exertion in relation to measured physiologic values during arm exercise. Future research studies could examine whether the RPE may be accurately used to prescribe and monitor appropriate exercise intensities during arm exercise with persons with poliomyelitis and whether submaximal perceptual responses reported during either an estimation or production procedure provide accurate predictions of $\dot{V}O_{2\text{max}}$, as demonstrated with able-bodied participants during cycle ergometry.^{13,14,35}

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Suppliers

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ORIGINAL ARTICLE

Prediction of peak oxygen uptake from ratings of perceived exertion during arm exercise in able-bodied and persons with poliomyelitis

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Study design: Each participant completed an arm-crank ramp exercise test to volitional exhaustion.

Objective: To assess the utility of the rating of perceived exertion (RPE) to predict peak oxygen uptake ($\dot{V}O_2$ peak) during arm ergometry in able-bodied participants and those with poliomyelitis.

Setting: University of Jordan, Amman, Jordan.

Participants: In all, 16 able-bodied and 15 participants with poliomyelitis completed an arm-crank ramp exercise test to volitional exhaustion.

Main outcome measures: The prediction of $\dot{V}O_2$ peak is calculated by extrapolating the sub-maximal RPE and $\dot{V}O_2$ values by linear regression to RPE 20.

Results: For the able-bodied participants, there were no significant differences between measured and predicted $\dot{V}O_2$ peak from the three sub-maximal ranges of the RPE (RPEs before and including RPE 13, 15 and 17, $P>0.05$). For the participants with poliomyelitis, the $\dot{V}O_2$ peak predicted from RPEs before and including RPE 13 was significantly higher than measured $\dot{V}O_2$ max ($P<0.05$). The 95% limits of agreement of able-bodied participants for RPE 13, 15 and 17 (-3 ± 14 , -1 ± 10 & $0 \pm 8 \text{ ml kg}^{-1} \text{ min}^{-1}$, respectively) were lower than those observed for poliomyelitis participants (6 ± 19 , 2 ± 12 and $1 \pm 9 \text{ ml kg}^{-1} \text{ min}^{-1}$, respectively).

Conclusion: This study has shown that the estimation of $\dot{V}O_2$ peak from submaximal RPE during arm ergometry is generally more accurate in able-bodied participants in comparison with those with poliomyelitis.

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Keywords: poliomyelitis; prediction of peak oxygen uptake; perceived exertion

Introduction

Maximal oxygen uptake ($\dot{V}O_2$ max) is the maximum rate at which an individual can take up and use oxygen during exercise involving large muscle groups.¹ Although a valuable indicator of cardiorespiratory endurance capacity and aerobic fitness,² the measurement of $\dot{V}O_2$ max is expensive and time consuming and requires a high degree of compliance from the individual involved. There are also practical concerns when conducting exhaustive exercise tests with non-athletic, elderly or patient populations.^{3,4} Accordingly, for reasons of cost, safety and time, it is sometimes preferable to estimate $\dot{V}O_2$ max using sub-maximal exercise procedures.³ On the basis of strong linear relationships between $\dot{V}O_2$ and heart rate (HR) and between $\dot{V}O_2$ and

the Borg 6–20 Rating of Perceived Exertion (RPE) Scale,⁵ it is possible to predict $\dot{V}O_2$ max from sub-maximal HR and/or the RPE.^{6,7}

Recent research has shown that $\dot{V}O_2$ values corresponding with sub-maximal RPE may be used to predict $\dot{V}O_2$ max when extrapolated to RPE 20 on the Borg 6–20 scale.^{6,8–10} To date, this has only been shown during cycle exercise with able-bodied, active, sedentary and obese participants.^{6,8–10} More accurate estimates of $\dot{V}O_2$ max have been shown from higher perceptual intensities (that is, RPE 9–17) as reflected by narrower limits of agreement (LoA) and higher intraclass correlations coefficient (ICC) between measured and predicted $\dot{V}O_2$ max.⁶ However, recent studies with low-fit men and women have shown accurate predictions of $\dot{V}O_2$ max from a single sub-maximal exercise test that uses a perceptual range up to and including RPE 13.^{6,8,9} The application of a lower perceptual range may be more appropriate for sedentary individuals or certain clinical populations as it may minimize the duration of the test, and ensure safe

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exercise performance.^{6,10} The RPE range between 12 and 15 equates to approximately 50–70% $\dot{V}O_{2\text{max}}$ in healthy able-bodied and paraplegic individuals.^{6,11,12}

It has been shown that RPE may provide estimates of $\dot{V}O_{2\text{max}}$ that are as accurate as those elicited from age-predicted maximal HR in able-bodied participants.⁹ However, the utility of age-predicted maximal HR may be limited in high-lesion paraplegic persons, as such individuals often show abnormal HR, hemodynamic (that is, blood distribution) and metabolic responses during exercise, most likely because of a loss of sympathetic innervation because of an impaired autonomic and motor nervous system.^{13,14}

As previous research has established the efficacy of using submaximal RPE to predict $\dot{V}O_{2\text{max}}$ during cycle ergometry with able-bodied participants, the purpose of this study was to assess the validity of this method for arm exercise in both able-bodied and poliomyelitis participants. We hypothesized that sub-maximal RPE values reported during arm exercise would provide an accurate prediction of $\dot{V}O_{2\text{peak}}$ in both groups irrespective of gender.

Materials and methods

Participants

In all, 16 men and women of able-bodied status, and 15 men and women with paraplegia (poliomyelitis), volunteered to take part in the study (Table 1). Individuals with poliomyelitis had flaccid paralysis of the lower limbs. Participation in the study was dependent on the participants providing written informed consent, being under the age of 45 years, no previous experience with arm-crank exercise or perceptual scaling, and no complications in the upper body, cardiovascular and cardiorespiratory systems and the torso. All participants had their blood pressure measured (Accoson, London, UK) before exercise participation. The study was conducted following institutional ethics approval from the Faculty of Physical Education at the University of Jordan, Amman, Jordan.

Procedures

All participants performed a single arm-cranking ramp exercise test designed to establish peak oxygen uptake ($\dot{V}O_{2\text{peak}}$) on a Lode arm ergometer (Lode, BV Medical Technology, Groningen, The Netherlands). The resistance on the ergometer was manipulated using the Lode Workload Programmer, accurate to $\pm 1\text{ W}$, which was independent of pedal cadence. Participants maintained a cadence of

50 rev min^{-1} throughout the exercise tests. On-line respiratory gas analysis occurred throughout each exercise test via a breath-by-breath automatic gas calibrator system (Quark, PFT 2 Ergo, Cosmed, Rome, Italy). Expired air was collected continuously using a facemask to allow participants to verbally communicate to the experimenter (that is, when reporting RPE). The system was calibrated (gas, pressure) before each exercise test in accordance with manufacturer's guidelines. A wireless chest strap telemetry system (Polar Electro T31, Kempele, Finland) continuously recorded HR during each exercise test. All physiological (HR, $\dot{V}O_2$, ventilation), respiratory exchange ratio and physical (work rate, time) outputs were concealed from the participants during the exercise tests.

Measures

Borg 6–20 RPE scale. Participants were familiarized with the Borg 6–20 RPE scale and were given standardized instructions on how to report their overall feelings of exertion before the test.⁵ Any questions regarding the scale were answered before exercise commenced. Participants were asked to appraise their overall perceived exertion during the remaining 20 s of each minute and at the termination of the exercise test.

Graded exercise test to establish $\dot{V}O_{2\text{peak}}$. The graded exercise test used a ramp protocol. Lambrick *et al.*⁹ postulated that the continuous change in workload may induce a more frequent appraisal of the feelings of exertion, thus facilitating more accurate estimates of $\dot{V}O_{2\text{peak}}$ in comparison with step-wise protocols. As recommended by the ACSM,⁴ pilot research was used to identify an increment in work rate that would enable $\dot{V}O_{2\text{peak}}$ to be ascertained within approximately 8–12 min during arm-crank exercise. In accordance with the ACSM guidelines, and after a 4-min warm up at 0 W, the work rate increased by 15 W min^{-1} and 6 W min^{-1} for able-bodied men and women, respectively. A 9 W min^{-1} increment for men with poliomyelitis, and 6 W min^{-1} increment for women with poliomyelitis, was considered to be more appropriate. During the last 20 s of each minute, and at the completion of the exercise test, participant's estimated their overall RPE. The termination of the exercise test was determined by a plateau in oxygen consumption, failure to maintain the required cadence or volitional cessation of the exercise test at exhaustion. An after exercise blood lactate concentration $\geq 8\text{ mmol l}^{-1}$ confirmed that participants achieved their maximal functional capacity.

Data analysis

Prediction of $\dot{V}O_{2\text{peak}}$ from RPE 13, 15 and 17. The mean $\dot{V}O_2$ recorded during the last 20 s of each minute was regressed against the corresponding RPE in a linear regression analysis for each participant. The corresponding individual coefficient of determination (R^2) was converted to an appropriate Fisher Zr transformation value to approximate the normality of the sampling distribution. When an RPE of 13, 15 or 17 had not been reported during the exercise test, linear regression analysis was used to determine the

Table 1 Demographic information (age, height, weight) for able-bodied and poliomyelitis men and women (mean \pm s.d.)

	Able-bodied men (n = 9)	Poliomyelitis men (n = 8)	Able-bodied women (n = 7)	Poliomyelitis women (n = 7)
Age (year)	20.3 ± 0.5	35.0 ± 4.0	20.8 ± 0.8	33.4 ± 5.0
Height (cm)	176.2 ± 6.0	168.0 ± 10.1	162.0 ± 6.4	147.4 ± 5.0
Weight (kg)	70.4 ± 17.1	71.0 ± 16.2	56.4 ± 7.6	55.1 ± 12.0

corresponding submaximal $\dot{V}O_2$ value ($\dot{V}O_2 = b(RPE 13, 15 \text{ or } 17) + c$). Individual linear regression analyses using the sub-maximal $\dot{V}O_2$ values elicited before and including an RPE 13, 15 and 17 were then extrapolated to RPE 20 on the Borg 6–20 RPE scale to predict $\dot{V}O_2\text{peak}$ (Figure 1).

Statistical analysis

A three-factor analysis of variance; method (four, measured $\dot{V}O_2\text{peak}$, predicted $\dot{V}O_2\text{peak}$ from RPEs up to and including 13, 15 and 17) \times participants' group (two, able-bodied and poliomyelitis) \times gender (two, male and female) compared measured and predicted $\dot{V}O_2\text{peak}$, and assessed whether gender and/or participants' group moderated these findings. The Mauchley test was used to confirm the assumptions of sphericity for repeated measures analysis of variance. When

this was not confirmed, the Greenhouse–Geisser correction factor was applied to increase the critical value of the F ratio. Tukey's *post hoc* tests were used to follow-up significant interactions. Alpha was set at 0.05 and adjusted accordingly. All data were analyzed using SPSS version 15.0 for windows.

Analysis of the consistency of the predictions in $\dot{V}O_2\text{peak}$

Bland and Altman¹⁵ 95% LoA analysis quantified the agreement (bias \pm random error) between measured and predicted $\dot{V}O_2\text{peak}$ for each RPE range. ICC was also used to quantify the relationship between predicted and measured values.

All applicable institutional and governmental regulations regarding the ethical use of human volunteers were followed during the course of this research.

Results

Descriptive statistics

Maximal physiological and RPE values are shown in Table 2. Individual linear regression analyses of individual RPE and $\dot{V}O_2$ values reported throughout the exercise test yielded an average R^2 value of 0.91. Similar R^2 values were observed for RPE and $\dot{V}O_2$ relationships reported before and including an RPE 13, 15 and 17 (all $R^2 > 0.86$). The $\dot{V}O_2$ and % $\dot{V}O_2\text{peak}$ observed at RPE 13, 15 and 17 are presented in Table 3.

Prediction of $\dot{V}O_2\text{peak}$ from RPE 13, 15 and 17

There were no significant differences between measured and predicted $\dot{V}O_2\text{peak}$ from sub-maximal RPE values before and including an RPE 13, 15 and 17 ($F_{(1,9,50,6)} = 0.81, P > 0.05$). The $\dot{V}O_2\text{peak}$ was significantly higher in men, regardless of group ($F_{(1,27)} = 5.5, P < 0.05$). There was a significant

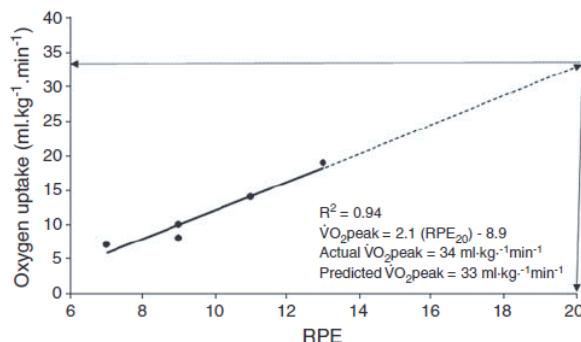


Figure 1 Example of predicting $\dot{V}O_2\text{max}$ using linear regression analysis. Sub-maximal $\dot{V}O_2$ values reported at RPE 7, 9, 11, and 13 are extrapolated to maximal RPE (RPE_{20}) on the Borg 6–20 scale to enable a prediction in $\dot{V}O_2\text{max}$.

Table 2 Descriptive statistics of maximal physiological values reported at the termination of the arm-crank test for able-bodied and poliomyelitis participants

	RPE max	$\dot{V}O_2\text{peak}$ ($\text{ml kg}^{-1}\text{min}^{-1}$)	HRmax (beats min^{-1})	RER max	$\dot{V}_E\text{max}$ (l min^{-1})
Able-bodied men	19.6 ± 0.7	28.4 ± 5.0	163 ± 19	1.08 ± 0.07	73 ± 17
Able-bodied women	19.6 ± 0.9	19.0 ± 2.2	161 ± 17	1.06 ± 0.08	41 ± 5
Poliomyelitis men	19.4 ± 1.1	24.0 ± 4.0	165 ± 14	1.05 ± 0.05	65 ± 18
Poliomyelitis women	18.7 ± 1.1	19.0 ± 4.1	155 ± 20	1.01 ± 0.09	43 ± 8

Abbreviations: HR, heart rate; RER, respiratory exchange ratio; RPE, rating of perceived exertion.

Data in Table 2 were presented in Al-Rahamneh et al.⁷

Table 3 Mean (\pm s.d.) $\dot{V}O_2$ values ($\text{ml kg}^{-1}\text{min}^{-1}$ and % $\dot{V}O_2\text{max}$) at RPE 13, 15 and 17 for able-bodied and poliomyelitis men and women

	RPE 13	RPE 15	RPE 17
	Mean \pm s.d. (%)	Mean \pm s.d. (%)	Mean \pm s.d. (%)
Able-bodied men	$14.3 \pm 5.6 (49.5 \pm 14.2)^a$	$19.2 \pm 5.7 (66.7 \pm 12.1)$	$22.6 \pm 6.4 (78.3 \pm 11.4)$
Able-bodied women	$12.1 \pm 1.2 (64.2 \pm 5.2)$	$14.1 \pm 2.1 (74.4 \pm 7.3)$	$16.0 \pm 2.6 (84.1 \pm 10.0)$
Poliomyelitis men	$16.8 \pm 6.5 (71.4 \pm 24.7)^b$	$18.5 \pm 5.3 (78.4 \pm 18.8)$	$21.0 \pm 5.2 (88.7 \pm 14.9)$
Poliomyelitis women	$12.9 \pm 7.3 (65.7 \pm 22.8)$	$14.6 \pm 7.0 (75.5 \pm 21.5)$	$16.5 \pm 5.8 (86.6 \pm 18.0)$

Abbreviation: RPE, rating of perceived exertion.

^aSignificant difference between men and women of able-bodied group $P < 0.05$.

^bSignificant difference between able-bodied and poliomyelitis men $P < 0.05$.

Table 4 Mean (\pm s.d.) measured and predicted $\dot{V}O_{2\text{max}}$ ($\text{ml kg}^{-1} \text{min}^{-1}$) for able-bodied and poliomyelitis participants

	Measured $\dot{V}O_{2\text{peak}}$	$\dot{V}O_{2\text{peak}} \text{ from RPE 13}$	$\dot{V}O_{2\text{peak}} \text{ from RPE 15}$	$\dot{V}O_{2\text{peak}} \text{ from RPE 17}$
Able-bodied men	28.4 ± 5.0	22.5 ± 10.4	26.6 ± 9.0	27.4 ± 8.3
Able-bodied women	19.0 ± 2.2	20.3 ± 5.0	20.2 ± 5.1	19.8 ± 4.5
Poliomyelitis men	24.0 ± 4.0	29.0 ± 10.5	25.9 ± 7.6	25.9 ± 6.5
Poliomyelitis women	19.0 ± 4.1	25.0 ± 13.8	20.0 ± 10.3	20.0 ± 8.6
Able-bodied participants	24.3 ± 6.2	21.5 ± 8.3	23.8 ± 8.0	24.0 ± 7.7
Poliomyelitis participants	21.4 ± 4.5	27.1 ± 11.9	23.1 ± 9.2	23.1 ± 7.9

Abbreviation: RPE, rating of perceived exertion.

interaction of group by method on $\dot{V}O_{2\text{peak}}$ ($F_{(1,9,50,6)} = 5.13$, $P < 0.05$). Post hoc analysis using Tukey's Honestly Significant Difference test showed that predicted $\dot{V}O_{2\text{peak}}$ from RPE up to and including 13 was significantly overestimated ($P < 0.05$) for individuals with poliomyelitis. There was no significant difference between group in $\dot{V}O_{2\text{peak}}$ ($F_{(1,27)} = 0.04$, $P > 0.05$) and no significant interactions for gender by method ($F_{(1,9,50,6)} = 1.37$, $P > 0.05$) or for gender by group by method on $\dot{V}O_{2\text{peak}}$ ($F_{(1,9,50,6)} = 0.76$, $P > 0.05$). Measured and predicted $\dot{V}O_{2\text{peak}}$ from the three RPE ranges are presented in Table 4.

Limits of agreement and ICCs

The 95% LoA were narrower in the able-bodied group ($\text{bias} \pm 1.96 \times \text{s.d.}_{\text{diff}}$, $\text{ml kg}^{-1} \text{min}^{-1}$) for RPE 13, 15 and 17 (-3 ± 14 , -1 ± 10 and $0 \pm 8 \text{ ml kg}^{-1} \text{min}^{-1}$, respectively) compared with the poliomyelitis participants (6 ± 19 , 2 ± 12 and $1 \pm 9 \text{ ml kg}^{-1} \text{min}^{-1}$, respectively). The reliability of predicting $\dot{V}O_{2\text{peak}}$ was also greater in the able-bodied participants (ICCs at RPE 13, 15 and 17 were 0.70, 0.85 and 0.91 (cf.) 0.61, 0.78 and 0.83, for the able-bodied and poliomyelitis participants, respectively).

Discussion

This study was conducted to investigate whether submaximal RPE and $\dot{V}O_2$ values elicited during arm-crank exercise with able-bodied and poliomyelitis participants could accurately predict $\dot{V}O_{2\text{peak}}$ when these values were extrapolated to RPE 20. The strong relationship between the Borg 6–20 RPE scale and $\dot{V}O_2$ was confirmed in this study with a high mean correlation of $R^2 = 0.91$ across the duration of the exercise test. Similar correlations were observed for the relationship between RPE and $\dot{V}O_2$ up to and including an RPE 13, 15 and 17 for both able-bodied participants and individuals with poliomyelitis ($R^2 > 0.86$).

The strong relationship between the RPE and $\dot{V}O_2$ supports previous research that has used the RPE during arm-crank exercise in individuals with SCI,¹² but do not concur with the suggestion that the RPE may not be a valid means of assessing or regulating exercise intensity in individuals with poliomyelitis or SCI.^{16,17} The equivocal observations may be attributed to the different exercise protocols used in these studies. Lewis *et al.*¹⁷ used a discontinuous arm-crank exercise test to examine the relationship between perceived exertion and physiologic indicators of stress, whereas this study used a ramp protocol to determine peak functional capacity.

The ACSM⁴ recommends that a combination of moderate intensity (that is, 40%–<60% of $\dot{V}O_2$ reserve) and vigorous intensity (that is, >60% of $\dot{V}O_2$ reserve) as a suitable exercise intensity range to enhance cardiorespiratory fitness. For each of the perceptual ranges, the mean relative $\dot{V}O_2$ (%) was similar for poliomyelitis men and women, and able-bodied women. Participants elicited a mean $\dot{V}O_2$ of 64–71% when exercising up to and including an RPE 13. These values are similar to those observed during a ramp exercise tests on a cycle ergometer.⁹ Although these participants exercised at a similar physiological intensity, less accurate estimates of $\dot{V}O_{2\text{peak}}$ were observed for individuals with poliomyelitis. Although participants with poliomyelitis will be more familiar with arm exercise, as it is the only mode of exercise that can be used for training and mobilization, they may have underestimated the RPE at a given work rate. This will have led to an overestimation of $\dot{V}O_{2\text{peak}}$. This was particularly evident for RPEs before and including RPE 13 when extrapolated to RPE 20.

In accordance with previous research, narrower LoA and stronger ICC were shown between measured and predicted $\dot{V}O_{2\text{peak}}$ from the higher perceptual ranges.⁶ The LoA for the predictions of $\dot{V}O_{2\text{peak}}$ from the lower perceptual range (RPE 13) for the able-bodied participants ($-3 \pm 14 \text{ ml kg}^{-1} \text{min}^{-1}$) are higher than those reported by Lambrick *et al.*⁹ during cycle exercise ($-0 \pm 6 \text{ ml kg}^{-1} \text{min}^{-1}$). The lower ICC for these data further substantiates this observation ($R = 0.70$ and $R = 0.94$, respectively). This may reflect that able-bodied participants are not as familiar with arm-crank exercise compared with leg cycling.

Our findings show that $\dot{V}O_{2\text{peak}}$ may be estimated with reasonable accuracy from a single, continuous ramp exercise test in able-bodied participants during arm exercise when extrapolated to RPE 20. The accuracy of estimating $\dot{V}O_{2\text{peak}}$ is improved when it is predicted from the higher perceptual ranges (up to and including RPE 15 and 17) regardless of participant group. However, there was considerable variability in the consistency of the predictions of $\dot{V}O_{2\text{peak}}$ particularly for the paraplegic participants. Furthermore, the prediction of $\dot{V}O_{2\text{peak}}$ from RPEs up to and including RPE 13 was significantly overestimated in the paraplegic participants. It is unknown if a period of practice in the reporting of RPE during arm-crank exercise would improve the prediction of $\dot{V}O_{2\text{peak}}$.

Conflict of interest

The authors declare no conflict of interest.

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ORIGINAL ARTICLE

Prediction of Peak Oxygen Consumption From the Ratings of Perceived Exertion During a Graded Exercise Test and Ramp Exercise Test in Able-Bodied Participants and Paraplegic Persons

Harran Q. Al-Rahamneh, MPE, Roger G. Eston, DPE

ABSTRACT. Al-Rahamneh HQ, Eston RG. Prediction of peak oxygen consumption from the ratings of perceived exertion during a graded exercise test and ramp exercise test in able-bodied participants and paraplegic persons. *Arch Phys Med Rehabil* 2011;92:277-83.

Objective: To assess the accuracy of predicting peak oxygen consumption ($\dot{V}O_2$ peak) from a graded exercise test (GXT) and a ramp exercise test during arm exercise in able-bodied persons and persons with paraplegia using ratings of perceived exertion (RPEs).

Design: Each participant performed a GXT (started at 30W and increased by 15W every 2min) and a ramp exercise test (started at 0W and increased by $15W \cdot min^{-1}$).

Setting: Universities' laboratories.

Participants: Able-bodied men (n=13; mean \pm SD, 27.2 \pm 4.3y) and men with paraplegia (n=12; 31.1 \pm 5.7y). Six of the persons with paraplegia had flaccid paraparesis as a result of poliomyelitis infection. The other 6 persons had complete spinal cord injuries with neurologic levels at and below T6.

Intervention: Not applicable.

Main Outcome Measures: Prediction of $\dot{V}O_2$ peak by extrapolating submaximal oxygen consumption ($\dot{V}O_2$) and RPE values to RPE 20 on the Borg 6 to 20 RPE scale.

Results: This study showed a very strong linear relationship between RPE and $\dot{V}O_2$ during the GXT and the ramp test for able-bodied persons ($R^2 \geq .95$ and $R^2 \geq .96$, respectively) and persons with paraplegia ($R^2 \geq .96$ and $R^2 \geq .95$, respectively). There was no significant difference between measured and predicted $\dot{V}O_2$ peak from RPEs before and including RPE 13, 15, and 17 during the GXT for persons with paraplegia ($P > .05$). For the able-bodied participants, there was no significant difference between measured and predicted $\dot{V}O_2$ peak from RPEs before and including RPE 15 and 17 during the ramp exercise test ($P > .05$).

Conclusion: The GXT provided acceptable predictions of $\dot{V}O_2$ peak for persons with paraplegia, and the ramp test provided acceptable predictions of $\dot{V}O_2$ peak for able-bodied persons.

Key Words: Arm ergometry; Oxygen consumption; Poliomyelitis; Spinal cord injuries.

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THE 6-20 RATING OF PERCEIVED exertion (RPE) scale¹ is frequently used to assess overall and localized perceived effort during exercise. It has been repeatedly shown that there is a very strong relationship between the RPE and PO, $\dot{V}O_2$, heart rate, and $\dot{V}E$ during leg cycling,^{2,3,4} running on a treadmill,^{5,6} and arm ergometry.^{7,8,9} On the basis of the strong linear relationship between the RPE and $\dot{V}O_2$, the RPE has been used to predict $\dot{V}O_2$ peak during leg cycling in healthy able-bodied participants,^{3,4,10} obese women,¹¹ and healthy young females during treadmill running.⁶ However, to our knowledge, there is no research that has assessed the usefulness of the RPE to predict $\dot{V}O_2$ peak during arm exercise in able-bodied people and persons with paraplegia.

The efficacy of using the RPE to regulate and prescribe exercise intensity in persons with paraplegia is not clear. Lewis et al¹² observed a poor relationship between the RPE and $\dot{V}O_2$ during a discontinuous incremental arm exercise test. Similarly, Jacobs et al¹³ recommended that heart rate but not RPE should be used to control exercise intensity in persons with paraplegia using functional neuromuscular stimulation. However, in a recent study by Goosey-Tolfrey et al,¹⁴ no significant differences were observed in heart rate, $\dot{V}O_2$, and blood lactate between imposed power based on 50% (moderate) and 70% (vigorous) peak oxygen consumption and RPE-regulated exercise intensities. In accordance with Goosey-Tolfrey,¹⁴ Al-Rahamneh et al⁹ also observed a strong linear relationship between the RPE and $\dot{V}O_2$ ($R^2 > .86$) during arm cranking using a ramp exercise test to volitional exhaustion in persons with poliomyelitis.

Maximal exercise testing is not recommended for some sedentary and clinical populations.¹⁵ In addition, depression is common in persons with paraplegia,^{16,17} which may in turn affect their motivation to perform a maximal exercise test. Therefore, the aim of this study was to assess the accuracy of predicting $\dot{V}O_2$ peak from a GXT and a ramp exercise test using

List of Abbreviations

ANOVA	analysis of variance
GXT	graded exercise test
ICC	intraclass correlation coefficient
LoA	limits of agreement
PO	power output
RER	respiratory exchange ratio
RPE	rating of perceived exertion
SCI	spinal cord injury
$\dot{V}E$	expired volume per unit time
$\dot{V}O_2$	oxygen consumption per unit time
$\dot{V}O_2$ peak	peak oxygen consumption per unit time

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Appendix 1C: Prediction of Peak Oxygen Uptake from a Ramp Exercise Test and Graded Exercise Test

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Table 1: Relevant Disability Descriptions for Persons With SCI

Participant No.	Lesion Level	Years Since Onset of SCI	Cause of Injury
1	T6, incomplete	25	Hit by a car
2	L1, complete	8	Motor vehicle collision
3	T7, complete	19	Fall
4	T11, complete	4	Motor vehicle collision
5	T6, complete	5	Accidental gun shot
6	T10, complete	7	Fall

submaximal RPE. We hypothesized that submaximal RPE and $\dot{V}O_2$ values would provide an acceptable prediction of $\dot{V}O_{2\text{peak}}$ when extrapolated to RPE 20 and that this would not be moderated by the exercise test (ie, GXT and ramp) or participants' group (ie, able-bodied and with paraplegia).

METHODS

Participants

Thirteen able-bodied men (mean \pm SD, 27.2 ± 4.3 y; 173.5 ± 4.9 cm; 74.5 ± 11.8 kg) and 12 men with paraplegia (31.1 ± 5.7 y; 170.5 ± 5.4 cm; 63.5 ± 11.5 kg) volunteered to take part in the study. Able-bodied participants were sport sciences students studying at the University of Exeter who were healthy and free from illnesses and preexisting injuries. Regarding persons with paraplegia, 6 of them had lower-limbs paralysis as a result of poliomyelitis infection, whereas the other 6 had SCI with neurologic levels at T6 and below (table 1). Able-bodied participants were physically active (>3 h/wk) but not arm-trained (eg, swimmer). Persons with paraplegia were physically active and participated in such sports as basketball, table tennis, weight lifting, and wheelchair racing at both professional and recreational levels. Arm ergometry was not a familiar mode of exercise training for both groups. On the first visit, all participants provided written informed consent and were measured for weight^a and blood pressure.^b Cholesterol and nonfasting blood glucose^c were also measured for all persons with paraplegia.

This study was conducted with joint institutional ethics approval from the University of Jordan and the School of Sport and Health Sciences at the University of Exeter. The exercise tests for the able-bodied participants and participants with paraplegia were conducted at the University of Exeter and the University of Jordan, respectively.

Procedures

Each participant (able-bodied and with paraplegia) performed 2 exercise tests. A ramp exercise test was performed to establish maximal functional capacity. A GXT was also performed to assess whether there was a difference in maximal values (ie, peak power output, $\dot{V}O_{2\text{peak}}$, and peak heart rate) between the GXT and the ramp exercise test. These 2 exercise tests were conducted in counterbalanced order to avoid an ordering effect. These exercise tests were also separated by 48 hours to allow enough recovery time. All participants were asked to avoid moderate and heavy exercise intensities prior to and between the exercise tests. All exercise tests were performed on the same Lode arm ergometer.^d The midpoint of the ergometer was set at shoulder level, and the distance was set to allow a slight flexion in the elbow when the arm was extended. The resistance on the ergometer was manipulated using the Lode Workload Programmer^d, accurate to ± 1 W, which was independent of pedal cadence. Participants were asked to keep the pedal cadence at 60 rpm during both exercise tests.

Online respiratory gas analysis occurred every 10 seconds throughout each exercise test via an automatic gas calibrator system.^e Expired air was collected using a facemask to allow the participants to report RPE. The system was calibrated prior to each exercise test using a 3-L syringe for volume calibration and the ambient air measure for gas calibration as recommended by the manufacturer's guidelines. The heart rate was recorded continuously during each exercise test using a wireless chest strap telemetry system.^f All physiologic (ie, heart rate, $\dot{V}O_2$, $\dot{V}E$, and RER), and physical (PO and time) variables were kept out of the participants' sight during all exercise tests.

Measures

Borg 6 to 20 RPE Scale. Participants were familiarized with the Borg 6 to 20 RPE scale and were given standardized instructions on how to report their overall feelings of exertion (overall RPE, ie, a rating of overall exertion which takes into account how hard breathing feels, how fatigued the arms feel, and how hot the participant feels) and their feelings of exertion in the arms only (peripheral RPE, ie, how fatigued the arms are) prior to each exercise test.¹ Any questions concerning the scale were answered before exercise commenced. Participants reported their overall and peripheral feeling of exertion in the remaining 20 seconds of each minute during the ramp exercise test and in the remaining 20 seconds of each stage during the GXT and at the completion of the exercise tests. Overall RPE was collected first.

Ramp Exercise Test. After warming up for 3 minutes at 0W, the exercise test started at 0W and was increased by 1W every 4 seconds ($15W \cdot min^{-1}$) until volitional exhaustion for both able-bodied persons and persons with paraplegia. During the last 20 seconds of every minute and at the completion of the exercise test, participants estimated their overall and peripheral RPE. The aim of this exercise test was to establish the peak functional capacity. The exercise test was terminated when participants were not able to keep the required pedal cadence or volitional exhaustion, although they were verbally encouraged to continue the exercise test.

Graded Exercise Test. After warming up for 3 minutes at 0W, the exercise test started at 30W and was increased by 15W every 2 minutes until volitional exhaustion for both able-bodied persons and persons with paraplegia. In the remaining 20 seconds of each stage and at the termination of the exercise test, participants were asked to estimate their overall and peripheral RPE. The aim of this exercise test was to assess whether there was a difference in the peak values of heart rate, $\dot{V}O_2$, $\dot{V}E$, and PO between the ramp exercise test and the GXT. The criteria for termination of the exercise test were similar to those reported for the ramp exercise test.

Data Analysis

A series of independent sample *t* tests revealed no significant differences between persons with polio and those with SCI in any of the physiologic variables (all $P > .05$). Therefore, they were combined in 1 group (ie, persons with paraplegia) for the following analysis (table 2).

GXT Versus Ramp Exercise Test. A series of 2-factor ANOVAs (test, GXT and ramp \times group; able-bodied and with paraplegia) were used to assess whether there was a difference in the maximal physiologic, physical, and perceptual values (ie, peak heart rate, $\dot{V}O_{2\text{peak}}$, peak power output, maximal RPE) observed at the termination of GXT and the ramp exercise test and between groups.

Overall RPE Versus Peripheral RPE. A series of paired sample *t* tests were used to compare whether there was a significant difference between overall RPE and peripheral RPE

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Table 2: Comparison Between Persons With SCI and Those With Polio in Demographic, Physical, Physiologic, and Perceptual Parameters

Group	Age (y)	Height (cm)	Weight (kg)	Peak Power Output (W)	Peak Ventilation (L·min ⁻¹)	Vo ₂ peak (mL·kg ⁻¹ ·min ⁻¹)	Peak Heart Rate (b·min ⁻¹)	RER	Overall RPE	Peripheral RPE
Polio	34.6±3.5*	171.0±6	66.2±11.1							
				98±16	89±15	34±6	171±14	1.24±0.09	19.0±0.6	19.7±0.5
	27.6±5.5	171.0±5	68.8±12.4	114±14	78±16	32±6	161±15	1.24±0.07	18.7±1.0	19.8±0.4
SCI	GXT									
				83±21	72±14	29±5	183±15	1.24±0.06	18.3±1.0	19.2±0.8
	Ramp									
				96±23	63±14	27±4	174±18	1.25±0.08	18.3±1.0	19.3±0.5

NOTE. Values are mean ± SD.

*Significant difference between individuals with SCI and those with polio ($P<.05$).

reported at the termination of the GXT and the ramp exercise test for able-bodied persons and persons with paraplegia.

Measured Versus Predicted Vo₂peak. The mean Vo₂ recorded during the last 20 seconds of each minute during the ramp exercise test and during the last 20 seconds of each stage during the GXT were regressed against the corresponding peripheral RPE in a linear regression analysis for each participant. The corresponding individual coefficient of determination (R^2) was converted to an appropriate Fisher Zr transformation value to approximate the normality of the sampling distribution.¹⁸ Where a peripheral RPE 13, 15, or 17 had not been reported during either the GXT or the ramp exercise test, linear regression analysis was used to determine the corresponding submaximal Vo₂ value ($\dot{V}O_2 = b$ [RPE 13, 15, or 17] + c). Individual linear regression analyses using the submaximal Vo₂ values elicited prior to and including a peripheral RPE 13, 15, and 17 were then extrapolated to the theoretic maximal RPE (RPE 20) on the Borg 6 to 20 RPE scale to predict Vo₂peak (fig 1).

A 3-factor ANOVA (test, GXT and ramp; method, measured Vo₂peak, predicted Vo₂peak from RPEs prior to and including RPE 13, 15, and 17; group, able-bodied and with paraplegia) was used to compare measured versus predicted Vo₂peak and whether that was moderated by the form of exercise test (ie, GXT, ramp) and/or participants' group. The assumptions of sphericity for all tests were checked using the Mauchly test. Where sphericity assumptions were not confirmed, the Greenhouse-Geisser epsilon was used to correct the degrees of freedom.¹⁹ All data were analyzed using SPSS for windows version 15.⁸

Analysis of the Consistency of the Predictions in Vo₂peak. A Bland and Altman²⁰ 95% LoA analysis quantified the agreement (bias ± 1.96 × SD difference) between measured and predicted Vo₂peak for each RPE range. ICC was also used to quantify the relationship between predicted and measured Vo₂peak values.

RESULTS

Descriptive Statistics of the Maximal Exercise Tests

The maximal physiologic (ie, Vo₂peak and peak heart rate), perceptual (ie, overall RPE and peripheral RPE), and physical (ie, PO) values observed at the termination of the GXT and the ramp exercise test are presented in table 3.

Participants achieved a significantly higher Vo₂peak during the GXT compared with the ramp exercise test ($F_{1,23}=19.9$; $P<.001$). There was no significant difference in Vo₂peak between the able-bodied participants and persons with paraplegia ($F_{1,23}=2.0$; $P>.05$) and no significant test by group interaction on Vo₂peak ($F_{1,23}=0.0$; $P>.05$). Similar results were observed for peak heart rate, which was also higher for the GXT ($F_{1,23}=23.7$; $P<.001$). There was no significant difference in peak heart rate between the able-bodied participants and persons with paraplegia ($F_{1,23}=3.8$; $P>.05$) and no significant test by group interaction on peak heart rate ($F_{1,23}=0.1$; $P>.05$). Further analysis showed that participants achieved a significantly higher peak power output during the ramp exercise test compared with the GXT ($F_{1,23}=110.1$; $P<.001$). It also showed that able-bodied participants achieved significantly higher peak power output during both exercise tests compared with persons with paraplegia ($F_{1,23}=18.2$; $P<.05$), and there was no significant test by group interaction on peak power output ($F_{1,23}=.781$; $P>.05$).

Participants reported similar overall RPEs ($F_{1,23}=1.8$; $P>.05$) and similar peripheral RPEs ($F_{1,23}=0.1$; $P>.05$) at the termination of the GXT and the ramp exercise test. There was also no significant test by group interaction on overall RPE ($F_{1,23}=0.3$; $P>.05$) or significant test by group interaction on peripheral RPE ($F_{1,23}=1.0$; $P>.05$).

However, paired sample *t* tests showed that able-bodied participants reported a significantly higher peripheral RPE compared with overall RPE at the termination of the GXT ($t_{12}=5.0$; $P<.001$) and the ramp exercise test ($t_{12}=5.8$; $P<.001$). Similar analysis showed that persons with paraplegia reported a significantly higher peripheral RPE compared with overall RPE at the termination of the GXT ($t_{11}=4.2$; $P<.01$) and the ramp exercise test ($t_{11}=5.6$; $P<.001$). As such, peripheral RPE was used to predict Vo₂peak during the GXT and the ramp exercise test for able-bodied participants and persons with paraplegia.

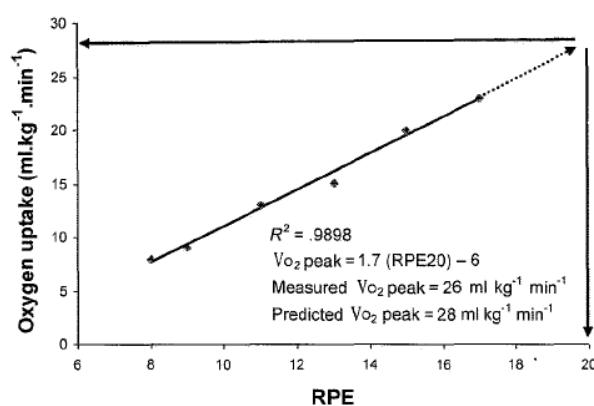


Fig 1. Prediction of Vo₂peak from RPEs prior to and including RPE 17 when extrapolated to RPE 20 from a ramp exercise test for a person with paraplegia.

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Table 3: Maximal Physiologic, Physical, and Perceptual Values Observed at the Completion of the GXT and the Ramp Exercise Test for Able-Bodied Persons and Persons With Paraplegia

Group	Peak Power Output (W)	Vo_2peak ($\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	Peak Heart Rate ($\text{b}\cdot\text{min}^{-1}$)	Overall RPE	Peripheral RPE
Able-bodied					
GXT	$118 \pm 16^*$	$34.5 \pm 7.0^*$	$167 \pm 14^*$	17.9 ± 1.6	$19.7 \pm 0.6^*$
Ramp	$136 \pm 14^*$	32.5 ± 5.8	156 ± 14	17.5 ± 1.5	$19.6 \pm 0.7^*$
Paraplegia					
GXT	90 ± 19	$31.1 \pm 6.1^*$	$177 \pm 15^*$	18.7 ± 0.9	$19.4 \pm 0.7^*$
Ramp	105 ± 20	29.1 ± 5.3	168 ± 17	18.5 ± 1.0	$19.6 \pm 0.5^*$

NOTE. Values are mean \pm SD.

*Significant difference between GXT and the ramp exercise test ($P < .05$).

^aSignificant difference between able-bodied persons and persons with paraplegia ($P < .05$).

^bSignificant difference between overall RPE and peripheral RPE ($P < .05$).

Measured Versus Predicted Vo_2peak

Measured and predicted Vo_2peak from the 3 RPE ranges (ie, RPEs prior to and including RPE 13, 15, and 17) for the GXT and the ramp exercise test for able-bodied participants and persons with paraplegia are presented in table 4.

There was no test by group interaction ($F_{1,23} = 0.0$; $P > .05$) and no test by method by group interaction ($F_{1,7,38,4} = 0.1$; $P > .05$) on Vo_2peak . However, there was a significant method by group interaction ($F_{3,69} = 7.1$; $P < .001$). The test by method interaction approached significance ($F_{1,7,38,4} = 3.2$; $P = .06$). Post hoc analysis using the Tukey honestly significant difference showed that predicted Vo_2peak from RPEs prior to and including RPE 13, 15, and 17 during the GXT and from RPEs up to and including RPE 13 during the ramp exercise test were significantly lower than measured Vo_2peak for able-bodied participants ($P < .05$). In addition, predicted Vo_2peak from RPEs prior to and including RPE 15 was significantly higher than measured Vo_2peak during the ramp exercise test for persons with paraplegia ($P < .05$).

Analysis of the Consistency of the Predictions in Vo_2peak

LoA and ICC between measured and predicted Vo_2peak from the 3 ranges of RPE (ie, before and including RPE 13, 15, and 17) when extrapolated to RPE 20 are presented in table 5. The assumption of homogeneity for the difference and the average between measured and predicted Vo_2peak was met for all the RPE ranges except during the GXT for persons with paraplegia for the RPE range before and including RPE 13. That was a result of a big difference between measured and predicted Vo_2peak for 1 participant. As such, we did not convert the data to log format, but we reported LoA for this perceptual range with and without this participant.

Comparison of % Vo_2peak at RPE 13, 15, and 17 during GXT and Ramp Exercise Test

There was no significant difference in proportions of Vo_2peak observed at RPE 13 between the GXT and the ramp exercise test ($F_{1,23} = 1.2$; $P > .05$) and no significant test by group interaction on % Vo_2peak ($F_{1,23} = 0.7$; $P > .05$). However, persons with paraplegia achieved a significantly higher % Vo_2peak at RPE 13 ($F_{1,23} = 28.2$; $P < .001$). Similar analysis revealed no significant difference in proportions of Vo_2peak observed at RPE 15 between the GXT and the ramp exercise test ($F_{1,23} = 2.6$; $P > .05$) and no significant test by group interaction on % Vo_2peak ($F_{1,23} = 0.1$; $P > .05$). However, persons with paraplegia achieved a significantly higher % Vo_2peak at RPE 15 ($F_{1,23} = 17.2$; $P < .001$). Further analysis showed no significant difference in the proportions of Vo_2peak observed at RPE 17 between the GXT and the ramp exercise test ($F_{1,23} = 3.0$; $P > .05$) and no significant test by group interaction on % Vo_2peak ($F_{1,23} = 0.2$; $P > .05$). However, persons with paraplegia achieved a significantly higher % Vo_2peak at RPE 17 ($F_{1,23} = 11.1$; $P < .01$). The mean % Vo_2peak \pm SD observed at peripheral RPE 13, 15, and 17 during the GXT and the ramp exercise test for able-bodied and persons with paraplegia are presented in table 6.

DISCUSSION

This study was conducted to assess whether a GXT or a ramp exercise test could provide an acceptable prediction of Vo_2peak using the RPE during arm exercise in able-bodied participants and those with paraplegia. In accordance with previous studies, the current study showed a very strong linear relationship between peripheral RPE and Vo_2 during the GXT and the ramp exercise test for able-bodied participants ($R^2 = .95$

Table 4: Vo_2peak ($\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) Observed at the Termination of the GXT and Ramp Exercise Test and Predicted Vo_2peak From RPEs Prior to and Including RPE 13, 15, and 17 for Able-Bodied Persons and Persons With Paraplegia

Group/Exercise	Measured Vo_2peak	Predicted From RPEs up to 13	Predicted From RPEs up to 15	Predicted From RPEs up to 17
Able-bodied				
GXT	34.5 ± 7.1	$30.2 \pm 7.7^*$	$29.7 \pm 6.5^*$	$30.6 \pm 5.6^*$
Ramp	32.5 ± 5.8	$28.5 \pm 5.1^*$	30.4 ± 5.4	31.7 ± 5.7
Paraplegia				
GXT	31.1 ± 6.1	32.3 ± 10.2	31.0 ± 7.5	31.0 ± 5.8
Ramp	29.1 ± 5.3	31.2 ± 8.5	$32.2 \pm 7.5^*$	31.4 ± 6.5

NOTE. Values are mean \pm SD.

*Significant difference between measured and predicted Vo_2peak ($P < .05$).

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Table 5: LoA and ICC Between Measured and Predicted $\dot{V}O_2$ peak From RPEs up to and Including RPE 13, 15, and 17 Extrapolated to RPE 20 for Able-Bodied Participants and Persons With Paraplegia for the GXT and the Ramp Exercise Test

Group	n	Measured and Predicted $\dot{V}O_2$ peak From RPEs up to 13	Measured and Predicted $\dot{V}O_2$ peak From RPEs up to 15	Measured and Predicted $\dot{V}O_2$ peak From RPEs up to 17
Able-bodied	13	-4±12	-5±8	-4±7
		.81	.89	.91
		-4±8	-2±8	-1±6
		.82	.85	.92
Paraplegic	12	-1±11	0±6	0±4
		.89	.94	.96
		-1±14	3±11	2±7
		.67	.77	.89

NOTE. Values are n or mean ± SD.

and $R^2 \geq .96$, respectively) and persons with paraplegia ($R^2 \geq .96$ and $R^2 \geq .95$, respectively).^{2,3,4,9,21}

GXT Versus Ramp Exercise Test

Participants, irrespective of group, achieved significantly higher maximal PO during the ramp exercise test compared with the GXT. However, time to exhaustion was significantly shorter during the ramp exercise test compared with the GXT for able-bodied persons (9.1min and 13.3min, respectively) and persons with paraplegia (7.0min and 9.4min, respectively). This is in accordance with previous research during leg cycling.²² This has an important application during arm exercise because it may minimize the effect of localized fatigue on termination of the exercise test. Nevertheless, participants, irrespective of group, achieved significantly higher peak heart rate and $\dot{V}O_2$ peak during the GXT compared with the ramp test. This is more likely attributed to the nature of the GXT, which allows more time for the heart rate and $\dot{V}O_2$ to reach a steady-state at each stage compared with the ramp test.²³

Predicted Versus Measured $\dot{V}O_2$ peak

Persons with paraplegia. For the persons with paraplegia, there was no significant difference between measured and predicted $\dot{V}O_2$ peak from the 3 RPE ranges (ie, RPEs before and including RPE 13, 15, and 17) when extrapolated to RPE 20 during the GXT. However, predicted $\dot{V}O_2$ peak from RPEs prior to and including RPE 15 during the ramp exercise test was significantly higher than measured $\dot{V}O_2$ peak from the ramp exercise test. A more accurate prediction of $\dot{V}O_2$ peak was elicited from higher perceptual ranges (ie, RPEs before and including RPE 17) during the GXT and the ramp exercise test as reflected by narrower LoA and higher ICC. The GXT provided a more accurate prediction of $\dot{V}O_2$ peak compared with the ramp test as reflected by no significant difference between measured and predicted $\dot{V}O_2$ peak from 3 RPE ranges, narrower LoA, and higher ICC. If the 1 participant who caused a heteroscedastic error in the perceptual range up to and including RPE 13 during the GXT is excluded, the LoA and ICC become 0±7 and .83, respectively.

The more accurate prediction of $\dot{V}O_2$ peak during the GXT compared with the ramp test might be attributed to the fact that more time was spent at each stage, which makes it easier to estimate the feeling of exertion. This observation is not in accordance with the findings of Lambrick et al,⁴ who stated that

a ramp exercise test provides a more accurate prediction of $\dot{V}O_2$ peak during leg cycling in healthy able-bodied participants because the continuous increase in the work rate may facilitate the appraisal of perceived exertion.

Able-bodied persons. For able-bodied participants, prediction of $\dot{V}O_2$ peak from RPEs prior to and including RPE 13, 15, and 17 were significantly lower compared with measured $\dot{V}O_2$ peak during the GXT. In addition, prediction of $\dot{V}O_2$ peak from RPEs prior to and including RPE 13 was significantly lower compared with measured $\dot{V}O_2$ peak during the ramp exercise test (see table 3). As expected, a more accurate prediction of $\dot{V}O_2$ peak was elicited from the higher perceptual ranges (ie, RPEs before and including RPE 17) during both exercise tests as reflected by narrower LoA and higher ICC. However, the ramp exercise test provided a more accurate prediction of $\dot{V}O_2$ peak as reflected by no significant difference between measured and predicted $\dot{V}O_2$ peak from RPEs up to and including RPE 15 and 17 and narrower LoA for the 3 RPE ranges compared with the GXT.

The lower predicted $\dot{V}O_2$ peak compared with the measured values in able-bodied participants might be attributed to 2 factors. First, able-bodied participants may have overestimated their peripheral RPE at a given work rate, which will have led to lower predicted $\dot{V}O_2$ peak compared with the measured value. Second, the higher measured $\dot{V}O_2$ peak compared with the predicted value is most likely attributed to the contribution of the torso at high intensities during the maximal exercise tests. Future studies should use belts, similar to those used in cars, to minimize the contribution of the torso during maximal exercise tests because the current study used belts to stabilize and minimize the contribution of the lower limbs only.

Proportion of $\dot{V}O_2$ peak at Peripheral RPE 13, 15, and 17

Persons with paraplegia exercised at ~65% $\dot{V}O_2$ peak at peripheral RPE 13 during both exercise tests. This is in accordance with previous research during leg cycling, treadmill running, and arm cranking.^{3,4,5,24,9} This intensity is considered effective because it may elicit cardiorespiratory adaptations, ensure the safe application of an exercise test, and improve the participants' adherence and sense of autonomy associated with exercise participation.^{24,25} The able-bodied participants exercised at ~52% $\dot{V}O_2$ peak at RPE 13, which was significantly lower than that observed for persons with paraplegia at the same RPE. This may be attributed to the able-bodied participants' relative lack of familiarity with arm exercise. The lower predicted $\dot{V}O_2$ peak from submaximal RPEs may also be attributed to this lack of familiarity. Nevertheless, the consistency of using the RPE to regulate exercise intensity during arm exercise in

Table 6: Percent $\dot{V}O_2$ peak at RPE 13, 15, and 17 During GXT and Ramp Exercise Test for Able-Bodied Participants and Persons With Paraplegia

Group/Exercise	% $\dot{V}O_2$ peak at RPE 13	% $\dot{V}O_2$ peak RPE 15	% $\dot{V}O_2$ peak RPE 17
Able-bodied			
GXT	52.4±4.8*	63.3±7.7*	77.0±8.3*
Ramp	51.9±7.2*	67.6±11.2*	80.2±7.9*
Paraplegic			
GXT	68.0±8.2	76.0±8.0	86.3±7.2
Ramp	64.5±10.9	78.9±9.0	88.3±6.3

NOTE. Values are n or mean ± SD.

*Significant difference between able-bodied persons and persons with paraplegia ($P < .01$).

able-bodied and persons with paraplegia is evident in the study because each group exercised at similar proportions of $\dot{V}O_2$ peak during both exercise tests at RPEs of 13, 15, and 17 (see table 6).

Peripheral Versus Overall RPE

Participants reported significantly higher peripheral RPE (19.6) compared with overall RPE (18.2) at the termination of the GXT and the ramp exercise test. To our knowledge, this is the first study that has looked into overall and peripheral RPE during arm exercise in persons with paraplegia. The higher peripheral RPE compared with overall RPE is in accordance with previous research.^{26,27} This is most likely attributed to the smaller muscle mass activated during arm exercise,²⁷ which may in turn reflect the higher work rate per unit of contracting muscles mass.²⁸ As such, it was more appropriate to use peripheral RPE, because overall RPE would eventually lead to an overestimation of $\dot{V}O_2$ peak.

Study Limitations

This study assessed the utility of the RPE to predict peak oxygen consumption in able-bodied and paraplegic persons. Because all paraplegic persons in this study were physically active, with some competing at a national level, the results are applicable for paraplegic persons who are physically active. They may not be directly applicable for sedentary paraplegic persons.

CONCLUSIONS

In conclusion, for the persons with paraplegia, the GXT provided a more accurate prediction of $\dot{V}O_2$ peak as reflected by the narrower LoA and higher ICC. However, for the able-bodied persons, the ramp test was more accurate at predicting $\dot{V}O_2$ peak as reflected by no significant difference between measured and predicted $\dot{V}O_2$ peak from RPEs prior to and including RPE 15 and 17 and narrower LoA for the 3 RPE ranges compared with the GXT. These observations have important implications in assessing maximal functional capacity in rehabilitation settings where maximal exercise testing is not feasible. In addition, the use of a submaximal exercise test will ensure a safer environment and may increase the participants' motivation to exercise by reducing the negative affect that might be associated with high exercise intensities.

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Appendix 1C: Prediction of Peak Oxygen Uptake from a Ramp Exercise Test and Graded Exercise Test

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ORIGINAL ARTICLE

The validity of predicting peak oxygen uptake from a perceptually guided graded exercise test during arm exercise in paraplegic individuals

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Study design: Each participant completed two submaximal, perceptually guided arm crank exercise tests and a graded exercise test (GXT) to volitional exhaustion.

Objective: To assess the validity of a submaximal, perceptually guided exercise test to predict peak oxygen uptake ($\dot{V}O_2\text{peak}$) during arm cranking in paraplegic individuals.

Setting: University of Jordan, Amman, Jordan.

Participants: Eleven men with paraplegia as a result of poliomyelitis infection or spinal cord injury completed two submaximal perceptually guided exercise tests and an arm crank GXT to volitional exhaustion.

Main outcome measures: The prediction of $\dot{V}O_2\text{peak}$ was calculated by extrapolating the submaximal rating of perceived exertion (RPE) and $\dot{V}O_2$ values by linear regression to RPE20.

Results: There were no significant differences between measured and predicted $\dot{V}O_2\text{peak}$ from the three submaximal ranges of the RPE (that is, 9–13, 9–15 and 9–17) when extrapolated to RPE20 during both perceptually guided exercise tests (all $P > 0.05$). However, the second perceptually guided exercise tests provided a more accurate prediction of $\dot{V}O_2\text{peak}$ as reflected by narrower 95% limits of agreement and higher intraclass correlation coefficients.

Conclusion: This study has shown that $\dot{V}O_2\text{peak}$ may be predicted with reasonable accuracy from a perceptually guided exercise test, especially after a full familiarization trial.

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Keywords: perceived exertion; paraplegic; peak oxygen uptake

Introduction

Maximal oxygen uptake ($\dot{V}O_2\text{max}$) is the highest rate of oxygen that a person can take up and utilize during exercise involving large muscle groups.¹ It is considered by most physiologists as the best indicator of cardiovascular and respiratory fitness.² It has also been indicated that $\dot{V}O_2\text{max}$ is an independent predictor of death in patients with heart disease.³ For reasons of cost and time, it is not always feasible to measure the $\dot{V}O_2\text{max}$. Therefore, on the basis of the strong linear relationship between heart rate (HR) and $\dot{V}O_2$, submaximal HR values are usually used to predict $\dot{V}O_2\text{max}$ by extrapolating these values to age-predicted maximal heart rate. However, individuals with high spinal cord injury (spinal cord injury $>T6$) have an abnormal HR response because of their injury. This may in turn affect the maximal

heart rate and consequently the ability to use age-predicted maximal heart rate to predict $\dot{V}O_2\text{max}$.

The Borg 6–20 Rating of Perceived Exertion (RPE) Scale⁴ is a widely accepted means of assessing the sensation of effort during exercise. The normal practice is to ask the person exercising to rate how hard the exercise feels while performing it. This procedure is frequently referred to as *estimation*, which is a passive process in which the RPE is free to vary. Conversely, the *production* procedure is an active process in which the RPE is prescribed and the individual produces an exercise intensity equating to a given RPE.

The RPE is a valid method of regulating exercise intensity using *estimation-production* procedures, whereby the exercise intensity is set according to a given RPE obtained from a previous exercise test in able-bodied and paraplegic individuals.^{5,6} Eston *et al.*⁷ showed that it is possible to apply the RPE production procedure in the form of a perceptually guided, graded exercise test to estimate the $\dot{V}O_2\text{max}$ by extrapolation of submaximal $\dot{V}O_2$ values elicited at RPEs of 9, 11, 13, 15 and 17 to RPE20 (that is, maximal RPE) on the Borg 6–20 RPE scale.

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The validity of the perceptually guided exercise test to predict $\dot{V}\text{O}_{2\text{max}}$ has been assessed in healthy low-fit individuals,⁸ across various exercise durations at each RPE level,⁹ in low-fit and physically active individuals,¹⁰ as well as in continuous and discontinuous protocols.^{7,8,11,12} The prediction of $\dot{V}\text{O}_{2\text{max}}$ from submaximal perceptually guided exercise bouts has been shown to be valid and facilitates a safer and more widely applicable means of exercise testing by eliminating higher exercise intensities (RPE >17) compared with the graded exercise test. A further advantage of this procedure is that individuals are given the autonomy to control the intensity of the exercise, and this may be an important factor for exercise adherence.

Individuals with spinal cord injury or spinal cord disease are generally less physically active compared with their able-bodied counterparts.^{13,14} Depressive symptoms are often prevalent among these individuals,¹⁵ which in turn may lead to a lack of motivation to exercise.¹⁶ As such, use of a perceptually guided exercise test to estimate $\dot{V}\text{O}_{2\text{peak}}$ at the beginning of an exercise program may be helpful from a motivational and self-autonomy perspective.

The aim of the current study was to assess whether $\dot{V}\text{O}_2$ values elicited during submaximal, perceptually guided exercise tests would provide an acceptable prediction of $\dot{V}\text{O}_{2\text{peak}}$ ($\dot{V}\text{O}_{2\text{peak}}$ is a preferred term for arm cranking ergometry due to the smaller muscle mass activated during this mode of exercise compared with leg cycling and running on a treadmill). We hypothesized that $\dot{V}\text{O}_2$ values elicited from submaximal, perceptually guided exercise bouts would provide an acceptable prediction of $\dot{V}\text{O}_{2\text{peak}}$ when extrapolated to RPE20 during arm cranking in paraplegic persons.

Methods

Participants

Eleven paraplegic men provided written informed consent for the study. Their demographic characteristics and lesions are presented in Table 1. All participants were physically active and participated in sports such as basketball, weight

lifting and wheelchair racing at professional and recreational levels. However, arm ergometry was not a familiar mode of exercise training for these individuals. On the first visit, the participants' weight (SECA, Hamburg, Germany) and blood pressure (Accoson, London, England) were measured. This study was conducted with institutional ethics approval from the faculty of physical education at the University of Jordan, where all the exercise tests were performed.

Procedures

Each participant completed two submaximal, perceptually guided exercise tests, separated by 48 h, to predict $\dot{V}\text{O}_{2\text{peak}}$. In addition, each participant performed an arm cranking GXT, separated by 48 h from the second perceptually guided exercise test, designed to establish $\dot{V}\text{O}_{2\text{peak}}$. In accordance with Morris *et al.*,¹¹ the perceptually guided exercise tests preceded the GXT, in order to not give the participants a complete familiarization with the full RPE scale, as sedentary and clinical populations may not experience this in real-life situations. All participants were recommended to avoid moderate and vigorous exercise in the days before and between the exercise tests, which were performed on a Lode arm ergometer (Lode, B.V. Medical Technology, Groningen, the Netherlands). The midpoint of the ergometer was set at shoulder level and the distance was set to allow a slight flexion in the elbow when the arm was extended. The resistance on the ergometer was manipulated using the Lode Workload Programmer, accurate to $\pm 1\text{ W}$, which was independent of pedal cadence. Participants were asked to keep the pedal cadence at 60 r.p.m.

On-line respiratory gas analysis occurred every 10 s throughout each exercise test by means of an automatic gas calibrator system (Cortex Metalyzer II, Biophysik, Leipzig, Germany). Expired air was collected using a facemask to allow the participants to report their RPE during the GXT and to direct the tester to increase or decrease the power output (PO) to satisfy the prescribed RPE levels during the perceptually guided tests. The system was calibrated before each exercise test using a 3-l syringe for volume calibration and ambient air, according to the manufacturer's

Table 1 Demographic, relevant disability descriptions and peak physical, physiological and perceptual responses during the GXT

Participants	Age (years)	Weight (kg)	Type of lesion	Lesion level	Years since injury	PO (W)	HR ($b\text{ min}^{-1}$)	$\dot{V}\text{O}_2$ ($\text{ml kg}^{-1} \text{min}^{-1}$)	\dot{V}_E ($L\text{ min}^{-1}$)	RER	RPEo	RPEp
1	34.0	69.0	Polio	—	—	105	173	32	70	1.14	19	19
2	34.7	79.9	Polio	—	—	105	159	27	95	1.29	20	20
3	34.8	60.0	Polio	—	—	90	168	33	87	1.22	18	19
4	31.0	59.8	SCI	T6	25	90	187	31	81	1.22	19	19
5	33.0	58.2	Polio	—	—	105	185	44	95	1.29	19	20
6	31.2	82.0	Polio	—	—	120	148	30	95	1.14	20	20
7	41.2	53.5	Polio	—	—	75	168	32	77	1.38	19	20
8	29.1	83.5	SCI	L1	8	105	170	26	89	1.28	17	19
9	29.9	49.4	SCI	T7	19	75	165	34	57	1.19	19	20
10	22.1	53.3	SCI	T11	4	60	178	24	65	1.34	19	19
11	24.3	59.7	SCI	T6	5	60	191	22	55	1.25	17	18
Mean	32.3	64.4	—	—	—	90	172	30.5	79	1.25	18.7	19.4
s.d.	4.7	12.3	—	—	—	20	13	5.9	15	0.08	1	0.7

Abbreviations: GXT, graded exercise test; HR, heart rate; L, lumbar; PO, power output; Polio, poliomyelitis; RER, respiratory exchange ratio; RPEo, overall rating of perceived exertion; RPEp, peripheral rating of perceived exertion; SCI, spinal cord injury; T, thoracic; \dot{V}_E , ventilation; $\dot{V}\text{O}_2$, oxygen uptake relative to body weight.

guidelines. Heart rate was recorded continuously using a wireless chest strap telemetry system (Polar Electro T31, Kempele, Finland). All physiological (that is, HR, oxygen uptake ($\dot{V}O_2$), ventilation (\dot{V}_E) and respiratory exchange ratio) and physical (PO and time) variables were kept out of sight during all exercise tests.

Measures

The Borg 6–20 RPE scale. Participants were given standardized instructions on how to report their overall and peripheral feelings of exertion before the GXT and how to use the overall RPE to regulate the exercise intensity during the perceptually guided exercise tests.⁴ Questions regarding the scale were answered before exercise commenced. Participants reported their overall and peripheral feeling of exertion in the remaining 20 s of each stage during the GXT and at the completion of the exercise test.

Perceptually guided exercise tests

In accordance with previous research,^{7–10} participants were asked to exercise for 3 min at exercise intensities equal to 9, 11, 13, 15 and 17 on the Borg 6–20 RPE Scale during the first perceptually guided exercise test. Increments of 10 W were used to increase the work rate between the prescribed RPE levels. If more resistance was needed, 5- and 3-W increments were used until the target RPE level was achieved. Participants were asked to feel free to ask the experimenter to amend the exercise intensity at any point during the 3-min stages to equate to their feeling of exertion at the prescribed RPE during each stage. Procedures for the second perceptually guided exercise were identical and aimed to assess whether the prediction of $\dot{V}O_2$ peak would improve with practice.

Graded exercise test

Each participant completed an arm crank GXT to establish $\dot{V}O_2$ peak. After a 3-min warm-up at 0 W, the exercise test started at 30 W, and increased by 15 W every 2 min until the participant reached volitional exhaustion or was unable to maintain the required pedal cadence. All participants were verbally encouraged to continue as long as possible. Participants were asked to report their overall and peripheral RPE during the last 20 s of each stage and at the completion of the exercise. If the participant completed 1 min at least during the last stage, it was considered to be the peak PO (POpeak), and the highest mean of $\dot{V}O_2$ recorded during the last 20 s of each stage was considered as the $\dot{V}O_2$ peak.

Data analysis

The mean $\dot{V}O_2$ values recorded during the last 20 s of the third minute at RPEs of 9, 11, 13, 15 and 17 during the perceptually guided exercise tests were regressed against the corresponding RPE in a linear regression analysis for each participant. Individual linear regression analyses using the submaximal $\dot{V}O_2$ values elicited in the RPE ranges RPE 9–13, 9–15 and 9–17 were then extrapolated to the theoretical maximal RPE (RPE20) on the Borg 6–20 RPE scale to predict $\dot{V}O_2$ peak (Figure 1). A series of paired sample *t*-tests were

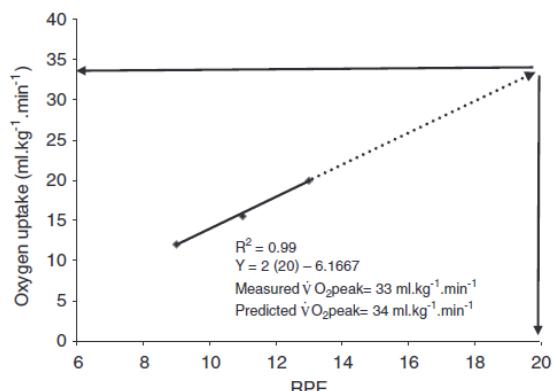


Figure 1 $\dot{V}O_2$ values elicited at RPEs of 9, 11 and 13 extrapolated to RPE20 on the Borg 6–20 RPE scale to predict $\dot{V}O_2$ peak for participant number 3.

used to compare predicted and measured $\dot{V}O_2$ peak from the three RPE ranges (that is, 9–13, 9–15 and 9–17). A series of paired sample *t*-tests were also used to compare %PO and % $\dot{V}O_2$ values observed at RPEs of 9, 11, 13, 15 and 17 between the two perceptually guided tests.

Bland and Altman¹⁷ 95% limits of agreement (LoA) analysis quantified the agreement (bias $\pm 1.96 \times$ s.d. difference) between measured and predicted $\dot{V}O_2$ peak for each RPE range. Data were checked for heteroscedasticity by conducting a Pearson correlation analysis between the difference of measured and predicted $\dot{V}O_2$ peak scores and the average of the two measurement scores before applying LoA analysis as recommended.¹⁷ Intraclass correlation coefficients were also calculated using a one-way random model to quantify the relationship between predicted and measured values.

Results

Descriptive statistics for peak values observed at the termination of GXT

Peak values observed at the termination of the GXT for physiological (that is, $\dot{V}O_2$, HR, ventilation (\dot{V}_E) and respiratory exchange ratio), physical (PO) and perceptual (overall RPE (RPEo) and peripheral RPE (RPEp)) variables are reported in Table 1.

Measured vs predicted $\dot{V}O_2$ peak

All measured and predicted $\dot{V}O_2$ peak values were normally distributed ($P > 0.05$) using Shapiro–Wilk statistics. Measured and predicted $\dot{V}O_2$ peak values from the three RPE ranges (that is, 9–13, 9–15 and 9–17) when extrapolated to RPE20 from both perceptually guided exercise tests are reported in Table 2.

There was no significant difference between measured and predicted $\dot{V}O_2$ peak from RPEs 9 to 15 ($t_{(10)} = 0.6$, $P = 0.583$) and from RPEs 9 to 17 ($t_{(10)} = 0.5$, $P = 0.633$), but the difference approached significance from RPEs 9 to 13 ($t_{(10)} = 2.2$, $P = 0.054$) during the first perceptually guided

Table 2 Measured and predicted $\dot{V}O_{2\text{peak}}$ ($\text{ml kg}^{-1} \text{min}^{-1}$) from the three ranges of the RPE (that is, 9–13, 9–15 and 9–17) from the first (P1) and second (P2) perceptually guided exercise tests

Trials	Measured $\dot{V}O_{2\text{peak}}$ ($\text{ml kg}^{-1} \text{min}^{-1}$)	Predicted $\dot{V}O_{2\text{peak}}$ from RPEs 9–13	Predicted $\dot{V}O_{2\text{peak}}$ from RPEs 9–15	Predicted $\dot{V}O_{2\text{peak}}$ from RPEs 9–17
P1	30.5 ± 5.9	27.4 ± 4.5	29.6 ± 5.9	29.9 ± 5.8
P2	30.5 ± 5.9	30.3 ± 6.0	30.2 ± 5.9	30.8 ± 5.9

Abbreviations; RPEs, rating of perceived exertions; $\dot{V}O_{2\text{peak}}$, maximal oxygen uptake.

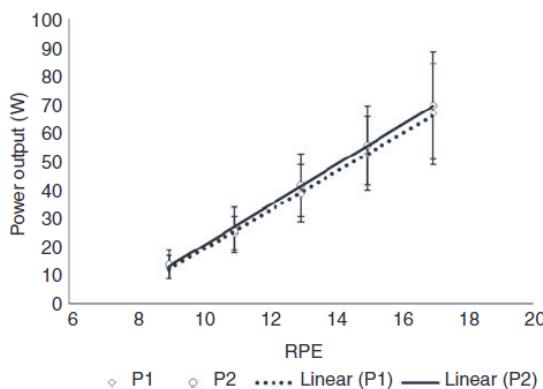


Figure 2 PO achieved at RPEs of 9, 11, 13, 15 and 17 during the first perceptually guided test (P1) and the second perceptually guided test (P2). Values are mean \pm s.d.

test. A similar analysis showed no significant difference between measured and predicted $\dot{V}O_{2\text{peak}}$ from RPEs 9 to 13 ($t_{(10)}=0.2, P=0.843$), RPEs 9 to 15 ($t_{(10)}=0.3, P=0.781$) and RPEs 9 to 17 ($t_{(10)}=0.4, P=0.687$) when extrapolated to RPE20 during the second perceptually guided test.

PO and $\dot{V}O_2$ observed at RPEs of 9, 11, 13, 15 and 17

PO increased linearly as a function of RPE during the two perceptually guided tests (Figure 2). The $\dot{V}O_2$ showed a similar pattern during both perceptually guided tests.

There were no significant differences in %PO observed at RPEs of 9, 11, 13, 15 and 17 between the two perceptually guided tests (All $P>0.05$). However, proportions of PO tended to be higher (~1 to ~4%) during the second perceptually guided test. A similar analysis revealed no significant difference in % $\dot{V}O_2$ observed at RPEs of 9, 11, 15 and 17 between the first and second perceptually guided tests. However, the % $\dot{V}O_2\text{peak}$ observed at RPE 13 was higher during the second perceptually guided test ($t_{(10)}=2.6, P=0.028$) and tended to be higher at RPEs of 15 and 17 during the second test.

Analysis of the consistency of the predictions of $\dot{V}O_{2\text{peak}}$

LoA and intraclass correlation coefficients between measured and predicted $\dot{V}O_{2\text{peak}}$ from the three RPE ranges during both trials are presented in Table 3. Figure 3 shows LoA

Table 3 LoA and ICC between measured and predicted $\dot{V}O_{2\text{peak}}$ from the three RPE ranges during both perceptually guided trials

	Measured and predicted $\dot{V}O_{2\text{peak}}$ from RPEs 9–13	Measured and predicted $\dot{V}O_{2\text{peak}}$ from RPEs 9–15	Measured and predicted $\dot{V}O_{2\text{peak}}$ from RPEs 9–17
P1 LoA	3.1 ± 9.2	0.9 ± 10.4	0.5 ± 6.9
P1 ICC	0.75	0.75	0.89
P2 LoA	0.2 ± 5.8	0.3 ± 6.2	0.4 ± 5.7
P2 ICC	0.94	0.92	0.94

Abbreviations: ICC, intraclass correlation coefficient; LoA, limits of agreement; RPEs, rating of perceived exertions; $\dot{V}O_{2\text{peak}}$, maximal oxygen uptake.

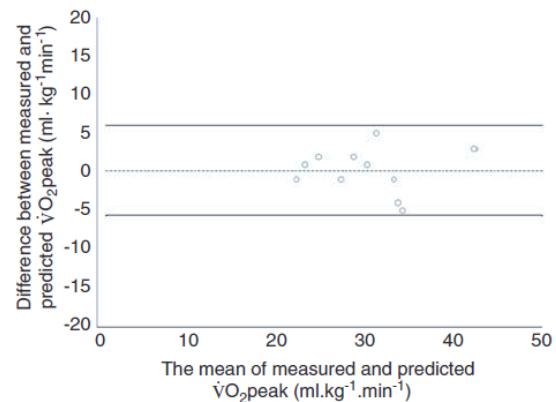


Figure 3 The 95% limits of agreement ($\text{bias} \pm 1.96 \times \text{SD}_{\text{diff}}$, $\text{ml kg}^{-1} \text{min}^{-1}$) for measured $\dot{V}O_{2\text{peak}}$ and predicted $\dot{V}O_{2\text{peak}}$ from RPEs 9–13 during the second perceptually guided exercise test.

between measured and predicted $\dot{V}O_{2\text{peak}}$ from RPEs 9 to 13 during the second perceptually guided test.

Discussion

This study showed very strong linear relationships between the RPE and $\dot{V}O_2$ values elicited from the GXT for the first and second perceptually guided tests (all $R^2 \geq 0.98$, when reconvert the mean of Fisher Zr values to their corresponding R^2). This finding is in accordance with previous research, which used a perceptually guided exercise test to predict $\dot{V}O_{2\text{max}}$ in healthy, able-bodied individuals during leg cycling.^{7–9}

There were no significant differences between measured and predicted $\dot{V}O_{2\text{peak}}$ values from the three RPE ranges (that is, RPEs 9–13, 9–15 and 9–17) when extrapolated to RPE20 from the two perceptually guided exercise tests. These findings are in agreement with previous research by Eston *et al.*^{7,9} The current study shows that the high RPE range (that is, RPE 9–17) may be excluded from the second perceptually guided test without loss of accuracy in predicting $\dot{V}O_{2\text{peak}}$. This is an important application for sedentary individuals and for clinical populations,^{12,18} although these observations are not in agreement with previous

observations. Eston *et al.*⁸ observed lower predicted $\dot{V}O_{2\text{max}}$ values from three production trials when an RPE of 17 was excluded. It should be borne in mind that all participants in this study were physically active, with some competing at the national level (for example, participant number 5 was a national level wheelchair racer). It is possible that the participants' familiarity with regular exercise in this study may affect their ability to perceptually regulate specific intensities according to a given, prescribed RPE. In this regard, Faulkner *et al.*,¹⁰ observed that able-bodied, physically active individuals showed less variability in reproducing a given exercise intensity at prescribed RPEs across several trials.

Nevertheless, it should be noted that, despite the non-significant differences between predicted and actual $\dot{V}O_{2\text{peak}}$ from the three RPE ranges, LoA and intraclass correlation coefficient analysis indicated that the prediction of $\dot{V}O_{2\text{peak}}$ was more accurate when estimated from the higher perceptual ranges (that is, RPEs 9–17) during the first perceptually guided test (Table 3). The second perceptually guided test also provided a more accurate prediction of $\dot{V}O_{2\text{peak}}$ as reflected by the closer measured and predicted $\dot{V}O_{2\text{peak}}$ values, narrower LoA and higher intraclass correlation coefficients (Tables 2 and 3).

This study shows the importance of using LoA to assess the agreement between the two methods of measuring the $\dot{V}O_{2\text{peak}}$. For instance, it seems from using the means and s.d. alone that the prediction of $\dot{V}O_{2\text{peak}}$ is very accurate, especially when estimated from the second production trial. However, when LoA was used to assess the accuracy of predicted $\dot{V}O_{2\text{peak}}$ against the measured value, there was a margin error of $\pm 6 \text{ ml kg}^{-1} \text{ min}^{-1}$ (20%) between measured and predicted $\dot{V}O_{2\text{peak}}$ for the three ranges of RPE.

In this study, participants exercised at higher % $\dot{V}O_{2\text{peak}}$ at RPEs of 9 (40%) and 11 (50%) compared with previous studies, which utilized a perceptually guided approach.^{7,8,10} This might be attributed to the lower mechanical efficiency during arm cranking compared with leg cycling as a result of recruiting additional muscles for stabilizing the torso and from static work of some muscle groups, which do not contribute to the external work rate.^{19,20}

In conclusion, this study has shown a very strong linear relationship between the RPE and $\dot{V}O_2$ during perceptually guided exercise tests. The results provide encouraging evidence that $\dot{V}O_{2\text{peak}}$ may be estimated with reasonable accuracy from submaximal $\dot{V}O_2$ values elicited during a perceptually guided exercise test, especially after a full familiarization trial. The results also imply that the higher RPE range (that is, RPEs 9–17) can be eliminated with little loss of accuracy in the prediction of $\dot{V}O_{2\text{peak}}$.

Conflict of interest

The authors declare no conflict of interest.

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Rating of perceived exertion during two different constant-load exercise intensities during arm cranking in paraplegic and able-bodied participants

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Abstract This study assessed the relationship between rating of perceived exertion (RPE) and time to exhaustion during arm cranking exercise while exercising at two different constant-load exercise intensities in able-bodied and paraplegic individuals. The second aim of this study was to assess the rate of change in the RPE between the two different constant-load exercise intensities in absolute and relative terms. Ten able-bodied men and ten paraplegic men performed four exercise tests: (1) a ramp exercise test (started at 0 W and increased by 15 W min^{-1}), (2) a graded exercise test (GXT) (started at 30 W and increased by 15 W every 2 min); these tests were performed in counterbalanced order, (3) a constant-load exercise test equal to 50% delta [i.e., the difference between the gas exchange threshold and peak power output (Δ)], (4) a constant-load exercise test equal to 70% Δ ; these tests were also performed in counterbalanced order. There was a strong linear relationship between the RPE and time to exhaustion ($R^2 \geq 0.88$) irrespective of exercise intensity and participants' group. As expected, the rate of change in the RPE was significantly greater during 70% Δ compared to 50% Δ when the RPE was regressed against absolute time regardless of group. However, differences in the rate of change in the RPE were removed when the RPE was regressed against proportion of time, irrespective of group. These findings have important implications for predicting time to exhaustion while exercising at constant-load

exercise intensity during arm cranking in able-bodied and paraplegic individuals.

Keywords Perceived exertion · Constant-load exercise · Arm cranking · Able-bodied · Paraplegic

Introduction

Several studies have observed that during prolonged submaximal exercise to exhaustion, the rating of perceived exertion (RPE) rises as a linear function of the percentage of total exercise duration. This was first observed by Horstman et al. (1979) in a study which required participants to walk or run at 80% of maximal functional capacity to 'self imposed exhaustion'. Noakes (2004) observation that the RPE data from the study by Baldwin et al. (2003) rose as a linear function of the duration of exercise that remained has inspired several studies to explore the phenomenon during running and cycling in able-bodied individuals (Crewe et al. 2008; Eston et al. 2007; Faulkner et al. 2008; Joseph et al. 2008). These studies have confirmed the original findings of Horstman et al. (1979). In this regard, it has been observed that the rate of increase in the RPE during self-paced (Faulkner et al. 2008; Joseph et al. 2008) or constant-load tasks (Crewe et al. 2008; Eston et al. 2007), where the participant exercises until volitional exhaustion or to a maximal or near-maximal RPE, is proportional to the time remaining on the task. In other words, when the RPE is expressed against the proportion (%) of the time completed, the rate of change in the RPE is similar. The scalar relationship between the RPE and time to volitional exhaustion, when exercising at a constant submaximal load during arm exercise in able-bodied and paraplegic individuals, is yet to be determined.

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It is well established that arm exercise elicits lower peak values for heart rate (HR), oxygen uptake ($\dot{V}O_2$), ventilation (\dot{V}_E) and power output (PO) compared to leg cycling (Aminoff et al. 1996; Franklin et al. 1983; Vander et al. 1984). However, HR, $\dot{V}O_2$, \dot{V}_E , RPE and blood lactate accumulation are higher at sub-maximal levels of arm exercise compared to leg cycling (Borg et al. 1987; Eston and Brodie 1986; Franklin et al. 1983; Vander et al. 1984). Therefore, it would be of interest to assess whether exercising with a smaller muscle mass (the arms) would affect the scalar property of the RPE.

Jacobs et al. (1997) and Lewis et al. (2007) reported poor relationships between the RPE and $\dot{V}O_2$ in individuals with spinal cord injury (SCI) during exercise involving functional neuromuscular stimulation and discontinuous, incremental arm cranking exercise, respectively. This would imply that the utility of the RPE is limited when applied with such populations. However, Goosey-Tolfrey et al. (2010) observed similar HR, $\dot{V}O_2$ and blood lactate levels during exercise intensities set at 50 and 70% $\dot{V}O_{2\text{peak}}$ compared to when the RPE from the two intensities was used to regulate exercise in well-trained paraplegic men. Müller et al. (2004) also observed similar RPE during two identical wheelchair exercise tests of $5 \times 1,500$ m in 11 wheelchair racers. These equivocal findings regarding the utility of the RPE in individuals with SCI might be attributed to the physical activity level of participants. The studies by Müller et al. (2004) and Goosey-Tolfrey et al. (2010) employed well-trained subjects, whereas, the studies by Jacobs et al. (1997) and Lewis et al. (2007) were based on less active participants. In addition, the study by Jacobs et al. (1997) employed shuttle-walking exercise using functional neuromuscular stimulation which might in turn affect the participants' ability to accurately appraise their RPE during exercise involving muscle groups below the lesion level.

The current study compared: (a) the relationship between RPE and time to volitional exhaustion while exercising at two different constant-load exercise intensities in able-bodied and paraplegic persons, and (b), the rate of change in RPE (beta coefficient) when regressed against time and %time to volitional exhaustion between the two constant-load exercise intensities.

Methods

Participants

Ten able-bodied men (25.7 ± 3.0 years, 173.3 ± 5.3 cm, 75.2 ± 13.5 kg) and 10 men with paraplegia (32.4 ± 5.3 years, 169.2 ± 6.7 cm, 63.3 ± 12.1 kg) volunteered to

take part in the study. Able-bodied participants were sport science students studying at the University of Exeter. Regarding those men with paraplegia, six had lower limbs flaccid paralysis as a result of poliomyelitis infection, and four had SCI with neurological levels at T6 and below (i.e., T6–L1) with duration since injury ranged between 4 and 25 years. Able-bodied participants were physically active (>3 h per week), but not specifically arm-trained (e.g., swimmer). Persons with paraplegia were physically active (>3 h per week) and participated in such sports as wheelchair basketball, weightlifting and wheelchair racing at both professional and recreational levels.

Arm ergometry was not a familiar mode of exercise training for both groups. On the first visit, all participants provided written informed consent and were measured for body mass (SECA, Hamburg, Germany), height and blood pressure (Accoson, London, England). For paraplegic individuals, body mass was measured while seated and height was measured in the supine position to the nearest 0.1 cm with a tape measure. This study was conducted with joint institutional ethics approval from the University of Jordan and the University of Exeter. Testing for all able-bodied participants took place in the School of Sport and Health Sciences at the University of Exeter. All exercise tests for paraplegic individuals took place in the Faculty of Physical Education at the University of Jordan.

Procedures

All participants performed four exercise tests. In the first two visits to the laboratory, the participant performed either a ramp exercise test to determine peak functional capacity or a GXT to ascertain true peak values (i.e., $\dot{V}O_{2\text{peak}}$ and HR_{peak}). These two exercise tests were conducted in counterbalanced order in order to avoid an ordering effect. Data from the ramp exercise test were also used to determine the constant-load exercise intensities for the two sub-maximal tests. The constant-load exercise tests were each performed to volitional exhaustion at 50 and 70% delta " Δ " (i.e., the difference between the gas exchange threshold "GET" and PO_{peak}). These two constant-load exercise tests were conducted in a counterbalanced order and separated by 48 h. Participants were asked to avoid moderate and heavy exercise intensities prior to and between the exercise tests.

All exercise tests were performed on the same Lode arm ergometer (Lode, B.V. Medical Technology, Groningen, Netherlands). The ergometer was stabilised on a table and a Biomedex chair (Biomedex Medical Systems, New York, USA) was used during all exercise tests for both able-bodied and paraplegic individuals. This chair has the advantage of moving forward, backward, and upward. For able-bodied

participants, straps were used to stabilise the legs and to minimise their contribution during the exercise tests. The midpoint of the ergometer was set at shoulder level and the distance was set to allow a slight flexion in the elbow when the arm was extended. The resistance on the ergometer was manipulated using the Lode Workload Programmer, accurate to ± 1 W, which was independent of pedal cadence. In accordance with previous research (Borg et al. 1987; Davies et al. 1990; Muraki et al. 2004; Wicks et al. 1983) and as we believe that it would be more difficult to maintain high pedal cadence (i.e., >60 rpm) during high intensity exercise, participants were requested to maintain the pedal cadence at 60 rpm.

On-line respiratory gas analysis occurred every 10 s throughout each exercise test via an automatic gas calibrator system (Cortex Metalyzer II, Biophysik, Leipzig, Germany). Expired air was collected using a facemask to allow the participants to report their RPE. The system was calibrated prior to each exercise test using a 3-L syringe for volume calibration and the ambient air measure for gas calibration as recommended by the manufacturer's guidelines. The HR was recorded continuously during each exercise test using a wireless chest strap telemetry system (Polar Electro T31, Kempele, Finland). All information pertaining to physiological (i.e., HR, $\dot{V}O_2$, \dot{V}_E and RER), physical (PO and time) variables were kept out of the participants' sight during all exercise tests.

Measures

Borg 6-20 RPE Scale

Participants were familiarized with Borg 6-20 RPE scale and were given standardised instructions on how to report their overall feelings of exertion (RPEo) and their feelings of exertion in the arms only (RPEp) prior to each exercise test (Borg 1998). Any questions concerning the scale were answered before exercise commenced. Participants reported their RPEo and RPEp at the completion of the exercise tests and in the remaining 20 s of each minute and each stage during the ramp exercise test and the GXT, respectively. However, the RPEo and RPEp were collected at random times during the two constant-load exercise tests and at the termination of the exercise test. This was done to avoid giving the participants information about the duration of time that had elapsed. RPEo was collected first.

Ramp exercise tests

After warming up for 3 min at 0 W, the exercise test started at 0 W and increased by 1 W every 4 s (15 W min^{-1}) until volitional exhaustion for both able-

bodied and paraplegic individuals. During the last 20 s of every minute and at the completion of the exercise test, participants estimated their RPEo and RPEp. The aim of this exercise test was to establish the peak functional capacity and to determine two different constant-load exercise intensities. The exercise test was terminated when the pedal cadence dropped by 5 rpm of the required rpm (i.e., 60) for a consecutive 20 s or volitional exhaustion, although participants were verbally encouraged to continue the exercise test.

Graded exercise test

After warming up for 3 min at 0 W, the exercise test started at 30 W and increased by 15 W every 2 min until volitional exhaustion for both able-bodied and paraplegic individuals. In the remaining 20 s of each stage and at the termination of the exercise test, participants were asked to estimate their RPEo and RPEp. The criteria of termination of the exercise test were similar to those reported for the ramp exercise test.

Constant-load exercise tests

Data from the ramp exercise tests were used to determine two different constant-load exercise intensities. After the GET and the PO_{peak} had been determined; 50 and 70% of the difference between the GET and the PO_{peak} were calculated and then added to the power output at the GET (i.e., 50 and 70% Δ). Participants were requested to exercise at these two constant-load exercise intensities until volitional exhaustion. They were also asked to estimate their RPEo and RPEp at random times in order to avoid giving them information about the duration had elapsed.

Determination of the gas exchange threshold

It has been indicated that the breakpoint between $\dot{V}O_2$ and $\dot{V}CO_2$ is clearer during the ramp exercise test compared to the step-wise exercise test (Jones et al. 2009). As such, data from the ramp exercise test were used to determine the GET for all participants. Two techniques were used to detect the GET: (1) V slope method which detects the onset of excess CO_2 output in response to lactate accumulation (Beaver et al. 1986). In this method the $\dot{V}CO_2$ (y axis) is regressed against the $\dot{V}O_2$ (x axis) and the first disproportionate increase in $\dot{V}CO_2$ relative to the $\dot{V}O_2$ is defined as the GET, (2) Ventilatory equivalent for oxygen uptake " $\dot{V}_E/\dot{V}O_2$ " and the ventilatory equivalent for carbon dioxide " $\dot{V}_E/\dot{V}CO_2$ " method (Caiozzo et al. 1982). In this method both the $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$ are regressed against time

Table 1 Peak values observed at the termination of the ramp exercise test and the GXT for able-bodied and paraplegic individuals

Group/exercise	$\dot{V}O_2$ peak ($L \text{ min}^{-1}$)	HR _{peak} ($b \text{ min}^{-1}$)	\dot{V}_E peak ($L \text{ min}^{-1}$)	RER	PO _{peak} (W)	RPEo	RPEp
Able-bodied							
GXT	2.58 ± 0.37* ^o	170 ± 13*	102 ± 17	1.13 ± 0.05	117 ± 14 ^o	17.9 ± 1.5	19.5 ± 0.7
Ramp	2.41 ± 0.31 ^o	159 ± 12	89 ± 18	1.16 ± 0.06	137 ± 11* ^o	17.5 ± 1.5	19.6 ± 0.7
Paraplegic							
GXT	2.00 ± 0.41*	172 ± 11*	80 ± 13	1.24 ± 0.08	95 ± 20	18.6 ± 1.0	19.2 ± 0.9
Ramp	1.89 ± 0.43	163 ± 13	70 ± 16	1.24 ± 0.08	108 ± 20*	18.4 ± 1.2	19.4 ± 1.0

Values are (Mean ± SD)

* Significant difference between ramp exercise test and GXT $P < 0.05$; ^o significant difference between able-bodied and paraplegic individuals $P < 0.05$

and the first point at which $\dot{V}_E/\dot{V}O_2$ starts to increase whilst $\dot{V}_E/\dot{V}CO_2$ decreases or fails to show a concomitant increase is defined as the GET.

Data analysis

A series of two-factor, mixed model ANOVAs (Test; ramp and GXT × group; able-bodied and paraplegic) were used to compare $\dot{V}O_2$ peak, HR_{peak} and PO_{peak} responses observed at the termination of the ramp exercise test and the GXT and between groups. Linear regression analyses were used to determine the individual relationships “ R^2 ” between time to exhaustion (x axis) and the RPE (y axis). As it has been shown that the data are not normally distributed in correlation coefficients (Thomas et al. 2005), the R^2 values were converted to Fisher Zr to approximate for the normality of data distribution. Furthermore, a two-factor ANOVA (intensity; 50 and 70% Δ × group; able-bodied and paraplegic) was used to compare time to exhaustion at 50 and 70% Δ and between groups.

Two-factor ANOVAs (intensity; 50 and 70% Δ × group; able-bodied and paraplegic) were used to compare the rate of change of the RPE (b coefficient) between 50 and 70% Δ when the RPE was regressed against time and proportion of time (%time) to exhaustion. In addition, three-factor ANOVAs (intensity; 50 and 70% Δ; Time 2 min in the exercise test and termination of the exercise test × group; able-bodied and paraplegic) were used to compare % $\dot{V}O_2$ peak and %HR_{peak} observed at 2 min in the exercise and at the termination of the exercise test and whether exercise intensity and/or participants' group moderated these findings.

Results

The peak physiological (i.e., $\dot{V}O_2$ HR, RER and \dot{V}_E), perceptual (i.e., RPEo and RPEp) and physical (i.e., PO)

values observed at the termination of the ramp exercise test and the GXT are presented in Table 1.

Participants achieved a significantly higher $\dot{V}O_2$ peak during the GXT compared to the ramp exercise test ($F_{(1,18)} = 21.3$, $P < 0.001$). Able-bodied participants achieved significantly higher $\dot{V}O_2$ peak compared to their paraplegic counterparts ($F_{(1,18)} = 10.6$, $P < 0.01$). However, there was no significant test × group interaction on $\dot{V}O_2$ peak ($F_{(1,18)} = 0.6$, $P > 0.05$). Similar analyses showed that participants achieved a significantly higher HR_{peak} during the GXT compared to the ramp exercise test ($F_{(1,18)} = 18.9$, $P < 0.05$). There was no significant difference in HR_{peak} between able-bodied and paraplegic participants ($F_{(1,18)} = 0.4$, $P > 0.05$) and no significant test × group interaction on HR_{peak} ($F_{(1,18)} = 0.3$, $P > 0.05$). Further analysis showed that participants achieved a significantly higher PO_{peak} during the ramp exercise test compared to the GXT ($F_{(1,18)} = 69.0$, $P < 0.001$) and able-bodied participants achieved a significantly higher PO_{peak} compared to paraplegic individuals ($F_{(1,18)} = 12.7$, $P < 0.01$). There was no significant test × group interaction on PO_{peak} ($F_{(1,18)} = 2.2$, $P > 0.05$).

Time to exhaustion, PO, the relationship (R^2) between RPEo and time to volitional exhaustion and between RPEp and time to volitional exhaustion for both exercise intensities (50 and 70% Δ) and for both groups are presented in Table 2.

Two-factor ANOVA showed that participants, regardless of group, exercised for a significantly longer duration at 50% compared to 70% Δ ($F_{(1,18)} = 29.0$, $P < 0.001$). Able-bodied participants exercised for significantly longer duration compared to those with paraplegia ($F_{(1,18)} = 6.0$, $P < 0.05$). Finally, there was a significant intensity × group interaction on exercise duration ($F_{(1,18)} = 6.0$, $P < 0.05$). Tukey's HSD showed that able-bodied participants exercised for significantly longer duration during the constant-load exercise test at 50% Δ compared to paraplegic individuals ($P < 0.05$).

Table 2 Power output (PO), time to exhaustion, the relationship (R^2) between RPEo and time to exhaustion and between RPEp and time to exhaustion for 50 and 70% Δ exercise intensities and for both groups

Group	PO (W)	Time to exhaustion (min)	R^2 (RPEo and time)	R^2 (RPEp and time)
Able-bodied				
50% Δ	82 ± 9	27.0 ± 15.0*	0.88	0.89
70% Δ	99 ± 10	9.4 ± 2.6	0.92	0.93
Paraplegic				
50% Δ	65 ± 16	14.6 ± 5.9*	0.92	0.89
70% Δ	78 ± 17	8.0 ± 2.5	0.94	0.92

* Significant difference between 50 and 70% Δ $P < 0.05$; ° Significant difference between able-bodied and paraplegic individuals $P < 0.05$

Two-factor ANOVAs revealed that the rate of change of RPEo was significantly greater when regressed against absolute time for the constant-load exercise intensity equating to 70% Δ ($b = 1.10 \pm 0.58$) compared to 50% Δ ($b = 0.53 \pm 0.45$), ($F_{(1,18)} = 59.5$, $P < 0.001$). Paraplegic individuals had a significantly greater rate of change in the RPEo compared to their able-bodied counterparts ($F_{(1,18)} = 6.8$, $P < 0.05$). There was no significant intensity \times group interaction on the rate of change in RPEo ($F_{(1,18)} = 0.3$, $P > 0.05$). Similar analyses showed a significantly greater rate of change in RPEp when regressed against absolute time for the constant-load exercise intensity equating to 70% Δ ($b = 1.10 \pm 0.63$) compared to 50% Δ ($b = 0.53 \pm 0.45$), ($F_{(1,18)} = 53.1$, $P < 0.001$). Paraplegic individuals had a significantly greater rate of change in the RPEp compared to their able-bodied counterparts ($F_{(1,18)} = 5.9$, $P < 0.05$). There was no significant intensity \times group interaction on the rate of change in RPEp ($F_{(1,18)} = 0.2$, $P > 0.05$).

All differences in the rate of change in RPEo and RPEp between the two constant-load exercise tests at 70 and 50% Δ and between able-bodied and paraplegic individuals were removed when the RPEo and RPEp were regressed against proportion of time (%time) to volitional exhaustion (all $P > 0.05$). Figures 1, 2, 3 and 4 elucidate the rate of change in RPEp against time and %time to volitional exhaustion in able-bodied and paraplegic individuals.

The physiological (i.e., % $\dot{V}O_2$ peak, %HR_{peak} and RER) and perceptual (RPEo and RPEp) variables observed at 2 min in the exercise and at the termination of the exercise test for both exercise intensities at 50 and 70% Δ for able-bodied and paraplegic individuals are presented in Table 3.

Three-factor ANOVA revealed that participants exercised at significantly higher % $\dot{V}O_2$ peak during the exercise test at 70% Δ compared to 50% Δ (% $F_{(1,18)} = 16.6$, $P < 0.01$). There was no significant difference between able-bodied and paraplegic individuals in % $\dot{V}O_2$ peak ($F_{(1,18)} = 2.0$, $P > 0.05$). The exercise test was terminated at a significantly higher % $\dot{V}O_2$ peak compared to % $\dot{V}O_2$ peak

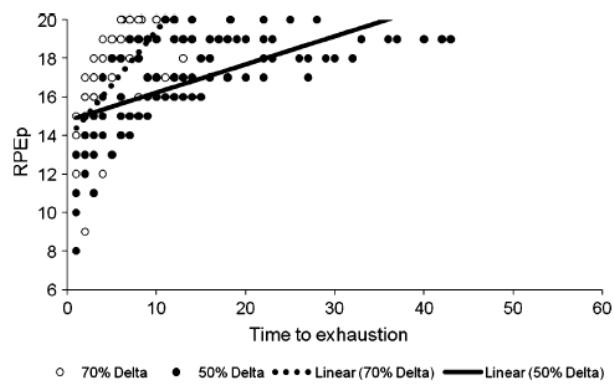


Fig. 1 The rate of change of the RPEp when regressed against time to exhaustion during both constant-load exercise intensities for able-bodied participants

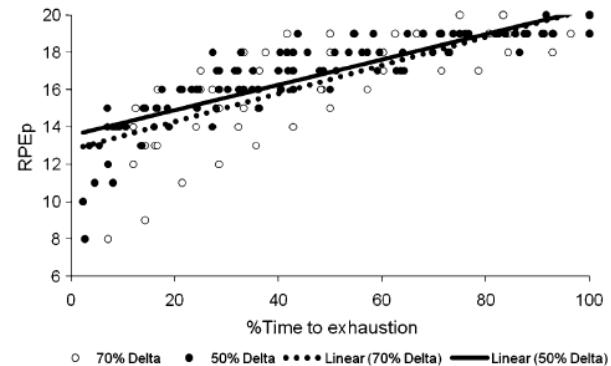


Fig. 2 The rate of change of the RPEp when regressed against %time to exhaustion during both constant-load exercise intensities for able-bodied participants

at 2 min in the exercise ($F_{(1,18)} = 38.3$, $P < 0.001$). There was no significant intensity \times group interaction on % $\dot{V}O_2$ peak ($F_{(1,18)} = 0.7$, $P > 0.05$) and no significant time \times group interaction on % $\dot{V}O_2$ peak ($F_{(1,18)} = 0.03$, $P > 0.05$). However, there was a significant intensity \times time interaction on % $\dot{V}O_2$ peak ($F_{(1,18)} = 17.5$,

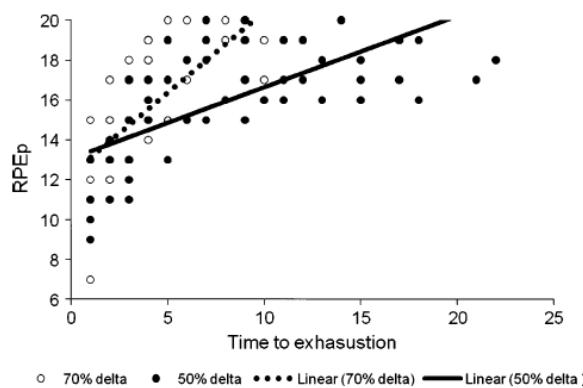


Fig. 3 The rate of change of the RPEp when regressed against time to exhaustion during both constant-load exercise intensities for paraplegic participants

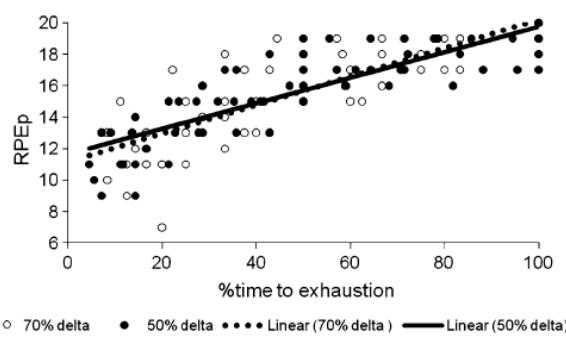


Fig. 4 The rate of change of the RPEp when regressed against %time to exhaustion during both constant-load exercise intensities for paraplegic participants

$P < 0.01$) and a significant intensity \times time \times group interaction on $\% \dot{V}O_2 \text{ peak}$ ($F_{(1,18)} = 4.9$, $P < 0.05$). Tukey's HSD revealed similar $\% \dot{V}O_2 \text{ peak}$ at 2 min in the exercise during both exercise intensities, but significantly

higher $\% \dot{V}O_2 \text{ peak}$ at the termination of the exercise test for 70% Δ compared to 50% Δ exercise test ($P < 0.05$).

Similar analysis revealed that participants exercised at significantly higher $\% HR_{\text{peak}}$ during the exercise test at 70% Δ compared to at 50% Δ ($F_{(1,18)} = 5.0$, $P < 0.05$). Although participants terminated the exercise test at significantly higher $\% HR_{\text{peak}}$ compared to $\% HR_{\text{peak}}$ at 2 min in the exercise ($F_{(1,18)} = 320.4$, $P < 0.001$), there was no significant difference between able-bodied and paraplegic individuals in $\% HR_{\text{peak}}$ ($F_{(1,18)} = 0.0$, $P > 0.05$). There was no significant intensity \times group interaction on $\% HR_{\text{peak}}$ ($F_{(1,18)} = 0.3$, $P > 0.05$) and no significant intensity \times time \times group on $\% HR_{\text{peak}}$ ($F_{(1,18)} = 1.1$, $P > 0.05$). However, there was a significant time \times group interaction on $\% HR_{\text{peak}}$ ($F_{(1,18)} = 11.4$, $P < 0.01$) and a significant intensity \times time interaction on $\% HR_{\text{peak}}$ ($F_{(1,18)} = 14.1$, $P < 0.01$). Tukey's HSD revealed that paraplegic participants exercised at significantly higher $\% HR_{\text{peak}}$ at 2 min in the exercise during the constant-load exercise test at 70% Δ compared to their able-bodied counterparts ($P < 0.05$). Further Tukey's HSD showed that participants terminated the exercise test at significantly higher $\% HR_{\text{peak}}$ during 70% compared to 50% Δ ($P < 0.05$).

Discussion

This study assessed the relationship between the RPE (i.e., RPEo and RPEp) and time to volitional exhaustion while exercising at two different constant-load exercise intensities equal to 50 and 70% Δ in able-bodied and paraplegic individuals. We also assessed the rate of change of the RPEo and RPEp against absolute time and %time to volitional exhaustion between the constant-load exercise tests at 50% and 70% Δ in these groups. The first main finding of this study is the strong linear relationship between the RPE and time to exhaustion during the constant-load

Table 3 Physiological variables (i.e., $\% \dot{V}O_2 \text{ peak}$, $\% HR_{\text{peak}}$, RER) observed at 2 min in the exercise and at the termination of the constant-load exercise tests at 50 and 70% Δ for able-bodied and paraplegic individuals

Group	$\% \dot{V}O_2 \text{ peak}$ (2 min)	$\% \dot{V}O_2 \text{ peak}$ final	$\% HR_{\text{peak}}$ (2 min)	$\% HR_{\text{peak}}$ final	RER final	RPEo final	RPEp final
Able-bodied							
50% Δ	73 \pm 14	81 \pm 12*	76 \pm 9	92 \pm 7*	0.98 \pm 0.05	17.7 \pm 2.0	19.7 \pm 0.5
70% Δ	72 \pm 15	92 \pm 9 ^o	75 \pm 6	97 \pm 4 ^o	1.06 \pm 0.05	17.5 \pm 2.1	19.9 \pm 0.3
Paraplegic							
50% Δ	74 \pm 7	86 \pm 7*	78 \pm 6	89 \pm 6*	1.03 \pm 0.02	18.4 \pm 1.1	19.0 \pm 1.2
70% Δ	81 \pm 8	96 \pm 4 ^o	79 \pm 7 ⁺	94 \pm 5 ^o	1.18 \pm 0.12	18.7 \pm 1.1	19.3 \pm 0.3

Values are (Mean \pm SD)

* Significant difference between 2 min in the exercise and termination of the exercise test $P < 0.05$; ^o significant difference between 50 and 70% Δ $P < 0.05$; ⁺ significant difference between able-bodied and paraplegic individuals $P < 0.05$

exercise test at 50% Δ ($R^2 \geq 0.88$) and 70% Δ ($R^2 \geq 0.92$) for able-bodied and paraplegic individuals. This is in accordance with previous observations during running and cycling in able-bodied individuals (Crewe et al. 2008; Horstman et al. 1979). The second main finding is the significantly greater rate of change in the RPE during the constant-load exercise test at 70% Δ compared to 50% Δ when the RPE was regressed against time. However, these differences in the rate of change of the RPE disappeared when the RPE was regressed against %time. This observation is in agreement with previous research during running and cycling in able-bodied individuals (Crewe et al. 2008; Eston et al. 2007; Faulkner et al. 2008; Joseph et al. 2008; Noakes 2004).

It has been indicated that ventilatory threshold and maximal lactate steady-state/critical power are better criteria to determine exercise intensity compared to $\dot{V}O_2$ peak alone (Katch et al. 1978). Katch et al. (1978) observed that at exercise equal to 80% HR_{peak} 17 out of 31 individuals were exercising above the $\dot{V}O_2$ at anaerobic threshold and the other 14 participants were exercising below the $\dot{V}O_2$ at anaerobic threshold. Therefore, the ventilatory threshold and PO_{peak} were used to determine the two different constant-load exercise intensities in this study. It has also been indicated that exercise in the severe domain is limited and predictable (Jones et al. 2009) which was the case during the constant-load exercise test at 70% Δ . Furthermore, the stronger relationship (although non-significant) between the RPE and time to exhaustion at 70% Δ compared to 50% Δ supports the notion by Noakes (2008) which stated that the RPE property to predict time to exhaustion to be stronger at higher intensities.

During the constant-load exercise test at 50% Δ , participants did not reach $\dot{V}O_2$ peak and the time to exhaustion was significantly longer than at 70% Δ (i.e., heavy domain). Able-bodied participants exercised for a significantly longer duration at 50% Δ compared to their paraplegic counterparts. This may reflect the fact that paraplegic individuals are not used to constant-load tasks as they do not push their wheelchairs constantly [i.e., the pushing action on the wheelchair is intermittent in nature (Sawka et al. 1980)]. This observation may also be attributable to the able-bodied participants being able to use their lower limbs for stabilisation and as a fulcrum from which to push (Janssen and Hopman 2005). This would have helped them to exercise for longer durations, especially when considering that participants did not achieve their $\dot{V}O_2$ peak or HR_{peak} at this exercise intensity.

It is important to note that participants reported peak RPEp (RPEp ≥ 19.0) at the termination of the constant-load exercise tests. This is in accordance with previous research at both constant work rate exercise tests (Eston

et al. 2007; Horstman et al. 1979) or graded exercise tests to volitional exhaustion to measure peak functional capacity in able-bodied (Faulkner and Eston 2007; Lambbrick et al. 2009) and paraplegic individuals (Al-Rahamneh et al. 2010). Regardless of group, all participants reported a higher RPEp at the termination of the exercise tests compared to RPEo. The higher RPEp compared to RPEo is in accordance with previous research by Demura and Nagasawa (2003) and Faulkner and Eston (2007). This might be attributed to the smaller muscle mass activated during the arm exercise (Borg et al. 1987; McArdle et al. 2007) and consequently the higher work per unit of contracting muscle mass (Åstrand et al. 2003).

In conclusion, this study showed that there is very strong linear relationship between the RPE (both RPEo and RPEp) and time to volitional exhaustion at constant-load exercise intensities during arm exercise in able-bodied and paraplegic individuals. It also showed that RPE increased at significantly higher rate of change during the constant-load exercise test at 70% Δ compared to 50% Δ when the RPE was regressed against time. However, these differences in the rate of change in the RPE between the two constant-load exercise intensities disappeared when the RPE was regressed against %time. These findings are in accordance with previous studies which have shown that the RPE scales with time while exercising at constant work rate under different conditions during leg cycling in healthy able-bodied participants (Eston et al. 2007; Noakes 2004). As such, this study confirms that the RPE scales with time while exercising at a constant work rate during arm cranking exercise in healthy able-bodied and paraplegic participants. This may indicate that the RPE is set at the beginning of the exercise and increases as a proportion of time completed or remaining regardless of the size of the muscle mass activated during exercise. This study has important implications for using the RPE as a sensitive predictor of time to exhaustion.

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Conflict of interest The authors do not have conflict of interest regarding this manuscript.

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Information sheet (study 1 and 2 for able-bodied and paraplegic individuals)

The relationship between perceived exertion and physical and physiological markers of exercise intensity during arm cranking and leg cycling in able-bodied and paraplegic individuals

Please read this information sheet carefully before deciding to take part in this study. The following information will inform 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 means how ‘hard’ or ‘easy’ an exercise feels to you. The sensation of breathlessness and fatigue in the exercising muscles are examples of factors that influence the perception of effort during exercise. Perceived exertion can be assessed using Borg 6-20 RPE Scale which contains descriptions at various points on the scale to help you evaluate how ‘hard’ or ‘easy’ the exercise feels. You will be asked to refer to this scale whilst you are exercising.

What is the aim of the study?

The purpose of this study is to investigate the relationship between the RPE and physical (i.e., power output) and physiological (i.e., heart rate, oxygen uptake and ventilation) markers of exercise intensity during leg cycling and arm cranking.

What participants are needed?

Paraplegic men and women as a result of poliomyelitis infection and able-bodied men and women who are physically active, under the age of 45, non-smoker, having no complications in the cardiovascular or cardiorespiratory system, $BMI < 30 \text{ kg.m}^{-2}$ and resting systolic blood pressure $< 140 \text{ mm Hg}$ and diastolic blood pressure $< 90 \text{ mm Hg}$ are required to participate in this study.

What will you have to do?

After you have provided informed consent to participate in this study, you will be requested to perform an arm cranking ramp exercise test, starts at 0 W and will increase by 6 W.min^{-1} for able-bodied and paraplegic women, 15 W.min^{-1} and 9 W.min^{-1} for able-bodied and paraplegic men, respectively, to volitional exhaustion to establish peak functional capacity (i.e., HRpeak and $\dot{V}\text{O}_2\text{peak}$) for the upper limbs. Able-bodied participants will also be asked to perform a leg cycling ramp exercise test, starts at 0 W

Appendix 2A: Information Sheet (study 1 and 2)

and will increase by $24 \text{ W} \cdot \text{min}^{-1}$ and $12 \text{ W} \cdot \text{min}^{-1}$ for men and women, respectively, to volitional exhaustion to establish maximal functional capacity (i.e., HRmax and $\dot{V}\text{O}_2\text{max}$) for the lower limbs. Volitional exhaustion is the point at which you feel that you can not continue beyond it.

Can participants change their mind and withdraw from the study?

Yes. Participants are free to withdraw from taking place in this study at any time without disadvantage or discrimination.

What will be done with the data?

Any data collected from this study will be stored in a safe place and only the researchers involved in the study will have access to these data. This data will be analyzed and only group mean data will be assessed to ease interpretation. The data will be used for research and publications purposes only. All data will be anonymous. Your name and your personal information will be concealed.

If you have any queries about this study, you can contact Harran Al-Rahamneh by e-mail: ha244@exeter.ac.uk or phone: 0777922985.

“This project has been reviewed and approved by the Faculty of Physical Education at the University of Jordan”

Information sheet (study 3 and 6 for paraplegic individuals)

Rating of perceived exertion during two different constant-load exercise intensities during arm cranking in paraplegic participants

Please read this information sheet carefully before deciding to take part in this study. The following information will inform 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 of how 'easy' or 'hard' it feels while exercising. The sensation of breathlessness and fatigue in the exercising muscles are examples of factors that influence the perception of effort during exercise. Perceived exertion can be assessed by a simple 15-point scale which contains descriptions at various points on the scale to help you evaluate how 'hard' or 'easy' the exercise feels. You will be asked to refer to this scale whilst you are exercising.

What is the aim of the study?

The purpose of this study is to investigate whether the RPE scales with time in paraplegic individuals during arm cranking exercise.

What participants are needed?

Men with paraplegia as a result of either spinal cord injury, complete or incomplete with neurological level at the sixth thoracic vertebra (T6) or below, or polio who are physically active, under the age of 45, non-smoker, having no complications in the cardiovascular or cardiorespiratory system, having normal blood glucose and cholesterol level, $BMI < 30 \text{ kg.m}^2$ and resting systolic blood pressure $< 140 \text{ mm Hg}$ and diastolic blood pressure $< 90 \text{ mm Hg}$ are required to participate in this study.

What will you have to do?

After you have provided informed consent to participate in this study, you will be requested to participate in four exercise tests, separated by a 48-h recovery period, in the physiology laboratory at the Faculty of Physical Education at the University of Jordan. In the first two visits you will be performing a ramp exercise test, starts at 0 W and will increase by 15 W.min^{-1} , to determine your peak functional capacity (i.e., HRpeak and $\dot{V}\text{O}_{2\text{peak}}$) and a graded exercise test (GXT), starts at 30 W and will increase by 15 W every two minutes, to ascertain that you will achieve your true peak

values. These two exercise tests will be performed in counterbalanced order. In two subsequent visits to the laboratory you will be asked to exercise at two different sub-maximal constant-load exercise intensities (50% and 70% delta; the difference between peak power output and the gas exchange threshold (GET)) to volitional exhaustion. The GET is when the exercise becomes more difficult. During each exercise test, you will be required to breathe through a specially designed respiratory valve so that the volume of air you breathe out can be measured and analysed for oxygen and carbon dioxide expired. In addition, you will be asked to report your overall RPE and the RPE in your arms at the end of every minute during the ramp exercise test and at the end of each stage during the GXT and at a random time during the two sub-maximal constant-load exercise tests.

Can participants change their mind and withdraw from the study?

Yes. Participants are free to withdraw from taking place in this study at any time without disadvantage or discrimination.

What will be done with the data?

Any data collected from this study will be stored in a safe place and only the researchers involved in the study will have access to these data. This data will be analyzed and only group mean data will be assessed to ease interpretation. The data will be used for research and publications purposes only. All data will be anonymous. Your name and your personal information will be concealed.

If you have any queries about this study, you can contact Harran Al-Rahamneh by e-mail: ha244@exeter.ac.uk or phone: 0777922985.

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Information sheet (study 3 and 6 for able-bodied participants)

Rating of perceived exertion during two different constant-load exercise intensities during arm cranking in able-bodied participants

Please read this information sheet carefully before deciding to take part in this study. The following information will inform 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 of how 'easy' or 'hard' it feels while exercising. The sensation of breathlessness and fatigue in the exercising muscles are examples of factors that influence the perception of effort during exercise. Perceived exertion can be assessed by a simple 15-point scale which contains descriptions at various points on the scale to help you evaluate how 'hard' or 'easy' the exercise feels. You will be asked to refer to this scale whilst you are exercising.

What is the aim of the study?

The purpose of this study is to investigate whether the RPE scales with time during arm cranking exercise in able-bodied participants.

What participants are needed?

Men who are physically active, under the age of 45, non-smoker, having no complications in the cardiovascular or cardiorespiratory system, having normal blood glucose and cholesterol level, $BMI < 30 \text{ kg.m}^2$ and resting systolic blood pressure $< 140 \text{ mm Hg}$ and diastolic blood pressure $< 90 \text{ mm Hg}$ are required to participate in this study.

What will you have to do?

After you have provided informed consent to participate in this study, you will be requested to participate in four exercise tests, separated by a 48-h recovery period, in the physiology laboratory at School of Sport and Health Sciences at the University of

Exeter. In the first two visits you will be performing a ramp exercise test, starts at 0 W and will increase by 15 W. min^{-1} , to determine your peak functional capacity (i.e., HRpeak and $\dot{V}\text{O}_{\text{peak}}$) and a graded exercise test (GXT), starts at 30 W and will increase by 15 W every two minutes, to ascertain that you will achieve your true peak values. These two exercise tests will be performed in counterbalanced order. In two subsequent visits to the laboratory you will be asked to exercise at two different sub-maximal constant-load exercise intensities (50% & 70% delta; the difference between peak power output and the gas exchange threshold (GET)) to volitional exhaustion. The GET is when the exercise becomes more difficult. During each exercise test, you will be required to breathe through a specially designed respiratory valve so that the volume of air you breathe out can be measured and analysed for oxygen and carbon dioxide expired. In addition, you will be asked to report your overall RPE and the RPE in your arms at the end of every minute during the ramp exercise test and at the end of each stage during the GXT and at a random time during the two sub-maximal constant-load exercise tests.

Can participants change their mind and withdraw from the study?

Yes. Participants are free to withdraw from taking place in this study at any time without disadvantage or discrimination.

What will be done with the data?

Any data collected from this study will be stored in a safe place and only the researchers involved in the study will have access to these data. This data will be analyzed and only group mean data will be assessed to ease interpretation. The data will be used for research and publications purposes only. All data will be anonymous. Your name and your personal information will be concealed.

If you have any queries about this study, you can contact:

Professor Roger Eston, Head of School and PhD supervisor by email:
r.q.eston@exeter.ac.uk or phone: (01392) 264720.

Harran Al-Rahamneh by e-mail: ha244@exeter.ac.uk or mobile: 07747000428.

“This project has been reviewed and approved by the Ethics Committee at School of Sport and Health Sciences at the University of Exeter”

Information sheet (study 4 for paraplegic individuals)

The validity of predicting peak oxygen uptake from a perceptually-guided, graded exercise test during arm exercise in paraplegic individuals

Please read this information sheet carefully before deciding to take part in this study. The following information will inform 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 of how 'easy' or 'hard' it feels while exercising. The sensation of breathlessness and fatigue in the exercising muscles are examples of factors that influence the perception of effort during exercise. Perceived exertion can be assessed by a simple 15-point scale which contains descriptions at various points on the scale to help you evaluate how 'hard' or 'easy' the exercise feels. You will be asked to refer to this scale whilst you are exercising. You will also be asked to use this scale to produce a level of exercise which you feel is commensurate with a specific number on the scale. Peak oxygen uptake ($\dot{V}O_2\text{peak}$) is the highest rate of oxygen that a person can take up and utilise during exercise. It has been indicated that $\dot{V}O_2\text{peak}$ is the best indicator of cardiorespiratory fitness. It has also been indicated that $\dot{V}O_2\text{peak}$ is an independent predictor of death in patients with heart disease as well as in all causes of death.

What is the aim of the study?

Previous studies have indicated that maximal oxygen uptake can be predicted with reasonable accuracy from a perceptually-guided, graded exercise test during leg cycling in healthy able-bodied participants. Therefore, the purpose of this study is to investigate whether peak oxygen uptake (the point of maximal volitional exhaustion) could be predicted from oxygen uptake values elicited from self-regulated sub-maximal, arm crank exercise in paraplegic individuals.

What participants are needed?

Men with paraplegia as a result of either spinal cord injury, complete or incomplete with neurological level at the sixth thoracic vertebra (T6) or below, or polio who are physically active (> 3 hours per week), under the age of 45, non-smoker, having no complications in the cardiovascular or cardiorespiratory system, having normal blood glucose and cholesterol level, BMI < 30 kg.m² and resting systolic blood pressure <

140 mm Hg and diastolic blood pressure < 90mm Hg are required to participate in this study.

What will you have to do?

After you have provided informed consent to participation in this study, you will be requested to participate in three exercise tests, separated by a 48-h recovery period, in the physiology laboratory at the Faculty of Physical Education at the University of Jordan. In the first two visits you will be asked to exercise at sub-maximal, self-regulated exercise intensities equal to ratings of perceived exertion (RPE) of 9, 11, 13, 15, and 17 on the Borg 6-20 RPE scale. These numbers equate to a range of exercise intensities ranging from an easy intensity to a harder intensity. You will be required to exercise for 3-min at each of the five intensities. In the last visit you will be asked to perform a graded exercise test to determine maximal functional capacity (maximal oxygen uptake ($\dot{V}O_2\text{max}$)). This test will be continuous and incremental in style, starting at a low intensity and becoming progressively harder (i.e. starts at 0 W and will increase by 15 W every two minutes until volitional exhaustion). During each exercise test, you will be required to breathe through a specially designed respiratory valve so that the volume of air you breathe out can be measured and analysed for oxygen and carbon dioxide expired.

Can participants change their mind and withdraw from the study?

Yes. Participants are free to withdraw from taking place in this study at any time without disadvantage or discrimination.

What will be done with the data?

Any data collected from this study will be stored in a safe place and only the researchers involved in the study will have access to these data. This data will be analyzed and only group mean data will be assessed to ease interpretation. The data will be used for research and publications purposes only. All data will be anonymous. Your name and your personal information will be concealed.

If you have any queries about this study, you can contact Harran Al-Rahamneh by e-mail: ha244@exeter.ac.uk or phone: 0777922428.

“This project has been reviewed and approved by the Faculty of Physical Education at the University of Jordan”



Information sheet (study 4 and 5b for able-bodied participants)

The validity of predicting peak oxygen uptake from a perceptually-guided, graded exercise test during arm exercise in able-bodied individuals

Please read this information sheet carefully before deciding to take part in this study. The following information will inform 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 of how 'easy' or 'hard' it feels while exercising. The sensation of breathlessness and fatigue in the exercising muscles are examples of factors that influence the perception of effort during exercise. Perceived exertion can be assessed by a simple 15-point scale which contains descriptions at various points on the scale to help you evaluate how 'hard' or 'easy' the exercise feels. You will be asked to refer to this scale whilst you are exercising. You will also be asked to use this scale to produce a level of exercise which you feel is commensurate with a specific number on the scale. Peak oxygen uptake ($\dot{V}O_2\text{peak}$) is the highest rate of oxygen that a person can take up and utilise during exercise. It has been indicated that $\dot{V}O_2\text{peak}$ is the best indicator of cardiorespiratory fitness. It has also been indicated that $\dot{V}O_2\text{peak}$ is an independent predictor of death in patients with heart disease as well as in all causes of death.

What is the aim of the study?

Previous studies have indicated that maximal oxygen uptake can be predicted with reasonable accuracy from a perceptually-guided, graded exercise test during leg cycling in healthy able-bodied participants. Therefore, the purpose of this study is to investigate whether peak oxygen uptake (the point of maximal volitional exhaustion) could be predicted from oxygen uptake values elicited from self-regulated sub-maximal, arm crank exercise in able-bodied participants.

What participants are needed?

Able-bodied men who are physically active, under the age of 45, non-smoker, having no complications in the cardiovascular or cardiorespiratory system, having normal

blood glucose and cholesterol level, BMI < 30 kg.m² and resting systolic blood pressure < 140 mm Hg and diastolic blood pressure < 90mm Hg are required to participate in this study.

What will you have to do?

After you have provided informed consent to participation in this study, you will be requested to participate in three exercise tests, separated by a 48-h recovery period, in the physiology laboratory at School of Sport and Health Sciences at the University of Exeter. In the first two visits you will be asked to exercise at sub-maximal, self-regulated exercise intensities equal to ratings of perceived exertion (RPE) of 9, 11, 13, 15, and 17 on the Borg 6-20 RPE scale. These numbers equate to a range of exercise intensities ranging from an easy intensity to a harder intensity. You will be required to exercise for 3-min at each of the five intensities. In the last visit you will be asked to perform a graded exercise test to determine maximal functional capacity (peak oxygen uptake ($\dot{V}O_2$ peak)). This test will be continuous and incremental in style, starting at a low intensity and becoming progressively harder (i.e., starts at 0 W and will increase by 15 W every two minutes until volitional exhaustion). During each exercise test, you will be required to breathe through a specially designed respiratory valve so that the volume of air you breathe out can be measured and analysed for oxygen and carbon dioxide expired.

Can participants change their mind and withdraw from the study?

Yes. Participants are free to withdraw from taking place in this study at any time without disadvantage or discrimination.

What will be done with the data?

Any data collected from this study will be stored in a safe place and only the researchers involved in the study will have access to these data. This data will be analyzed and only group mean data will be assessed to ease interpretation. The data will be used for research and publications purposes only. All data will be anonymous. Your name and your personal information will be concealed.

Prof. Roger Eston, Head of School and PhD supervisor by email: r.g.eston@exeter.ac.uk or phone: (01392) 264720.

Harran Al-Rahamneh (PhD student) by e-mail: ha244@exeter.ac.uk or mobile: 07747000428.

“This project has been reviewed and approved by the Ethics Committee at School of Sport and Health Sciences at the University of Exeter”

Informed consent (study 1 and 2 for able-bodied and paraplegic individuals)

The relationship between perceived exertion and physiological markers of exercise intensity during arm cranking and leg cycling in able-bodied and paraplegic individuals

I have read the information sheet concerning this study and I understand what it is about. The aims of this project and the procedures involved have been plainly explained to me. All my questions have been answered to my satisfaction. I know that I will perform an arm cranking ramp exercise test in the physiology laboratory at the Faculty of Physical Education at the University of Jordan to volitional exhaustion. The aim of this exercise test is to establish peak functional capacity (i.e., HRpeak and $\dot{V}O_2$ peak) for the upper limbs. For able-bodied participants, I know that I will also perform a leg cycling ramp exercise test to volitional exhaustion to establish peak functional capacity (i.e., HRpeak and $\dot{V}O_2$ peak) for the lower limbs.

In addition, I agree that:

- The information I give will be used only for research and publications purposes for the researchers involved in this study at the School of Sport and Health Sciences.
- My data will be coded and will not be identified and only the named researchers will have access to the data.
- I have the right to see my data and the results of the study and to withdraw from the study at any time without any disadvantage.
- I understand that there will not be remuneration for taking part in the study.

I,.....(name) agree to take part in the above mentioned study:

Signed(participant) Date.....

Informed consent (study 3 and 6 for paraplegic individuals)

Rating of perceived exertion during two different constant-load exercise intensities during arm cranking in paraplegic individuals

I have read the information sheet concerning this study and I understand what it is about. The aims of this project and the procedures involved have been plainly explained to me. All my questions have been answered to my satisfaction. I know that I will participate in four exercise tests in the physiology laboratory at the Faculty of Physical Education at the University of Jordan. Each exercise test will be separated by a 48- h recovery period; I will be required to perform:

- A ramp arm crank exercise test to establish peak functional capacities (i.e., HRpeak and $\dot{V}O_2$ peak) and to determine two different constant-load exercise intensities (50% and 70% delta; the difference between maximal work rate and the gas exchange threshold). A graded arm crank exercise test to ensure you will achieve your true peak values (i.e., HRpeak and $\dot{V}O_2$ peak). These two exercise tests will be continuous and incremental in style, starting at a low intensity and becoming progressively harder, to the point at which I cannot continue at the required cadence. These two tests will be performed in a counterbalanced order.
- Two sub-maximal constant-load exercise tests at 50% and 70% delta to volitional exhaustion.

In addition, I agree that:

- The information I give will be used only for research and publications purposes for the researchers involved in this study at the School of Sport and Health Sciences at university of Exeter.
- My data will be coded and will not be identified and only the named researchers will have access to the data.
- I have the right to see my data and the results of the study and to withdraw from the study at any time without any disadvantage.
- I understand that there will not be remuneration for taking part in the study.

I,.....(name) agree to take part in the above mentioned study:

Signed.....(participant) Date.....



Informed consent (study 3 and 6 for able-bodied participants)

Rating of perceived exertion during two different constant-load exercise intensities during arm cranking in able-bodied participants

I have read the information sheet concerning this study and I understand what it is about. The aims of this project and the procedures involved have been plainly explained to me. All my questions have been answered to my satisfaction. I know that I will participate in four exercise tests in the physiology laboratory at the School of Sport and Health Sciences at the University of Exeter. Each exercise test will be separated by a 48- h recovery period; I will be required to perform:

- A ramp arm crank exercise test to establish peak functional capacities (i.e., HRpeak and $\dot{V}O_2$ peak) and to determine two different constant-load exercise intensities (50% and 70% delta; the difference between maximal work rate and the gas exchange threshold). A graded arm crank exercise test to ensure you will achieve your true peak values (i.e., HRpeak and $\dot{V}O_2$ peak). These two exercise tests will be continuous and incremental in style, starting at a low intensity and becoming progressively harder, to the point at which I cannot continue at the required cadence. These two tests will be performed in a counterbalanced order.
- Two sub-maximal constant-load exercise tests at 50% and 70% delta to volitional exhaustion.

In addition, I agree that:

- The information I give will be used only for research and publications purposes for the researchers involved in this study at the School of Sport and Health Sciences.
- My data will be coded and will not be identified and only the named researchers will have access to the data.
- I have the right to see my data and the results of the study and to withdraw from the study at any time without any disadvantage.
- I understand that there will not be remuneration for taking part in the study.

I,.....(name) agree to take part in the above mentioned study:

Signed(participant) Date.....

Informed consent (study 4 for paraplegic individuals)

The validity of predicting peak oxygen uptake from a perceptually-guided, graded exercise test during arm exercise in paraplegic individuals

I have read the information sheet concerning this study and I understand what it is about. The aims of this project and the procedures involved have been plainly explained to me. All my questions have been answered to my satisfaction. I know that I will participate in three exercise tests in the physiology laboratory at the Faculty of Physical Education at the University of Jordan. Each exercise test will be separated by a 48-h recovery period; I will be required to perform:

- Two sub-maximal arm crank exercise tests, both of which will be regulated by the Borg 6-20 ratings of perceived exertion (RPE) scale. During these tests I will exercise at 5 different perceptual intensities (3-min at each intensity), ranging from a light/easy perception of effort to a progressively harder feeling.
- A graded arm crank exercise test to ascertain peak oxygen uptake. This will be continuous and incremental in style, starting at a low intensity and becoming progressively harder, to the point at which I cannot continue at the required cadence.

In addition, I agree that:

- The information I give will be used only for research and publications purposes for the researchers involved in this study at the School of Sport and Health Sciences at the University of Exeter.
- My data will be coded and will not be identified and only the named researchers will have access to the data.
- I have the right to see my data and the results of the study and to withdraw from the study at any time without any disadvantage.
- I understand that there will not be remuneration for taking part in the study.

I,.....(name) agree to take part in the above mentioned study:

Signed(participant) Date.....



Informed consent (study 4 and 5b for able-bodied participants)

**The validity of predicting peak oxygen uptake from a perceptually-guided,
graded exercise test during arm exercise in able-bodied participants**

I have read the information sheet concerning this study and I understand what it is about. The aims of this project and the procedures involved have been plainly explained to me. All my questions have been answered to my satisfaction. I know that I will participate in three exercise tests in the physiology laboratory at School of Sport and Health Sciences at the University of Exeter. Each exercise test will be separated by a 48-h recovery period; I will be required to perform:

- Two sub-maximal arm crank exercise tests, both of which will be regulated by the Borg 6-20 ratings of perceived exertion (RPE) scale. During these tests I will exercise at 5 different perceptual intensities (3-min at each intensity), ranging from a light/easy perception of effort to a progressively harder feeling.
- A graded arm crank exercise test to ascertain peak oxygen uptake. This will be continuous and incremental in style, starting at a low intensity and becoming progressively harder, to the point at which I cannot continue at the required cadence.

In addition, I agree that:

- The information I give will be used only for research and publications purposes for the researchers involved in this study at the School of Sport and Health Sciences.
- My data will be coded and will not be identified and only the named researchers will have access to the data.
- I have the right to see my data and the results of the study and to withdraw from the study at any time without any disadvantage.
- I understand that there will not be remuneration for taking part in the study.

I,.....(name) agree to take part in the above mentioned study:

Signed(participant) Date.....

Appendix 4: Table Used to Transfer r values to Fisher Zr

Table used to transform correlation coefficients (r) to Fisher Zr values to approximate for normality distribution. Note: modified from Research Method in Physical Activity (Thomas et al. (2005, pp. 412)).

r	Zr	r	Zr	r	Zr	r	Zr
0.400	0.424	0.550	0.618	0.700	0.867	0.850	1.256
0.405	0.430	0.555	0.626	0.705	0.877	0.855	1.274
0.410	0.436	0.560	0.633	0.710	0.887	0.860	1.293
0.415	0.442	0.565	0.640	0.715	0.897	0.865	1.313
0.420	0.448	0.570	0.648	0.720	0.908	0.870	1.333
0.425	0.454	0.575	0.655	0.725	0.918	0.875	1.354
0.430	0.460	0.580	0.662	0.730	0.929	0.880	1.376
0.435	0.466	0.585	0.670	0.735	0.940	0.885	1.398
0.440	0.472	0.590	0.678	0.740	0.950	0.890	1.422
0.445	0.478	0.595	0.685	0.745	0.962	0.895	1.447
0.450	0.485	0.600	0.693	0.750	0.973	0.900	1.472
0.455	0.491	0.605	0.701	0.755	0.984	0.905	1.499
0.460	0.497	0.610	0.709	0.760	0.996	0.910	1.528
0.465	0.504	0.615	0.717	0.765	1.008	0.915	1.557
0.470	0.510	0.620	0.725	0.770	1.020	0.920	1.589
0.475	0.517	0.625	0.733	0.775	1.033	0.925	1.623
0.480	0.523	0.630	0.741	0.780	1.045	0.930	1.658
0.485	0.530	0.635	0.750	0.785	1.058	0.935	1.697
0.490	0.536	0.640	0.758	0.790	1.071	0.940	1.738
0.495	0.543	0.645	0.767	0.795	1.085	0.945	1.783
0.500	0.549	0.650	0.775	0.800	1.099	0.950	1.832
0.505	0.556	0.655	0.784	0.805	1.113	0.955	1.886
0.510	0.563	0.660	0.793	0.810	1.127	0.960	1.946
0.515	0.570	0.665	0.802	0.815	1.142	0.965	2.014
0.520	0.576	0.670	0.811	0.820	1.157	0.970	2.092
0.525	0.583	0.675	0.820	0.825	1.172	0.975	2.185
0.530	0.590	0.680	0.829	0.830	1.188	0.980	2.298
0.535	0.597	0.685	0.838	0.835	1.204	0.985	2.443
0.540	0.604	0.690	0.848	0.840	1.221	0.990	2.647
0.545	0.611	0.695	0.858	0.845	1.238	0.995	2.994