

## 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 ( $-3 \pm 14$ ,  $-1 \pm 10$  &  $0 \pm 8$  ml kg<sup>-1</sup> min<sup>-1</sup>, respectively) were lower than those observed for poliomyelitis participants ( $6 \pm 19$ ,  $2 \pm 12$  and  $1 \pm 9$  ml kg<sup>-1</sup> min<sup>-1</sup>, 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.<sup>1</sup> Although a valuable indicator of cardiorespiratory endurance capacity and aerobic fitness,<sup>2</sup> 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.<sup>3,4</sup> Accordingly, for reasons of cost, safety and time, it is sometimes preferable to estimate  $\dot{V}O_2$ max using sub-maximal exercise procedures.<sup>3</sup> 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,<sup>5</sup> it is possible to predict  $\dot{V}O_2$ max from sub-maximal HR and/or the RPE.<sup>6,7</sup>

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.<sup>6,8–10</sup> To date, this has only been shown during cycle exercise with able-bodied, active, sedentary and obese participants.<sup>6,8–10</sup> 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.<sup>6</sup> 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.<sup>6,8,9</sup> 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.<sup>6,10</sup> The RPE range between 12 and 15 equates to approximately 50–70%  $\dot{V}O_2$ max in healthy able-bodied and paraplegic individuals.<sup>6,11,12</sup>

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 HR in able-bodied participants.<sup>9</sup> 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.<sup>13,14</sup>

As previous research has established the efficacy of using submaximal RPE to predict  $\dot{V}O_2$ 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  $\dot{V}O_2$ 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 ( $\dot{V}O_2$ 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  $\pm 1$  W, which was independent of pedal cadence. Participants maintained a cadence of

50 rev min<sup>-1</sup> 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.<sup>5</sup> 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  $\dot{V}O_2$ peak.** The graded exercise test used a ramp protocol. Lambrick *et al.*<sup>9</sup> 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 with step-wise protocols. As recommended by the ACSM,<sup>4</sup> pilot research was used to identify an increment in work rate that would enable  $\dot{V}O_2$ 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<sup>-1</sup> and 6 W min<sup>-1</sup> for able-bodied men and women, respectively. A 9 W min<sup>-1</sup> increment for men with poliomyelitis, and 6 W min<sup>-1</sup> 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  $\geq 8$  mmol<sup>-1</sup> confirmed that participants achieved their maximal functional capacity.

### 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*<sup>2</sup>) 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

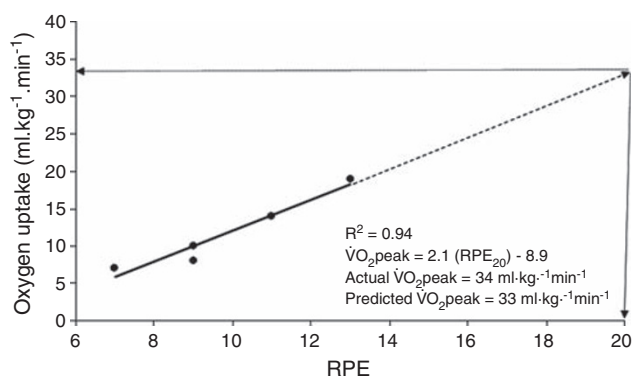
**Table 1** Demographic information (age, height, weight) for able-bodied and poliomyelitis men and women (mean  $\pm$  s.d.)

	Able-bodied men (n = 9)	Poliomyelitis men (n = 8)	Able-bodied women (n = 7)	Poliomyelitis women (n = 7)
Age (year)	20.3 $\pm$ 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
Weight (kg)	70.4 $\pm$ 17.1	71.0 $\pm$ 16.2	56.4 $\pm$ 7.6	55.1 $\pm$ 12.0

corresponding submaximal  $\dot{V}O_2$  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 before and including an RPE 13, 15 and 17 were then extrapolated to RPE 20 on the Borg 6–20 RPE scale to predict  $\dot{V}O_{2peak}$  (Figure 1).

### Statistical analysis

A three-factor analysis of variance; method (four, measured  $\dot{V}O_{2peak}$ , predicted  $\dot{V}O_{2peak}$  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  $\dot{V}O_{2peak}$ , and assessed whether gender and/or participants' group moderated these findings. The Mauchly test was used to confirm the assumptions of sphericity for repeated measures analysis of variance. When



**Figure 1** Example of predicting  $\dot{V}O_{2max}$  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<sub>20</sub>) on the Borg 6–20 scale to enable a prediction in  $\dot{V}O_{2max}$ .

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 $\dot{V}O_{2peak}$

Bland and Altman<sup>15</sup> 95% LoA analysis quantified the agreement (bias  $\pm$  random error) between measured and predicted  $\dot{V}O_{2peak}$  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 % $\dot{V}O_{2peak}$  observed at RPE 13, 15 and 17 are presented in Table 3.

### Prediction of $\dot{V}O_{2peak}$ from RPE 13, 15 and 17

There were no significant differences between measured and predicted  $\dot{V}O_{2peak}$  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  $\dot{V}O_{2peak}$  was significantly higher in men, regardless of group ( $F_{(1, 27)} = 5.5$ ,  $P < 0.05$ ). There was a significant

**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	$\dot{V}O_{2peak}$ (ml kg <sup>-1</sup> min <sup>-1</sup> )	HRmax (beats min <sup>-1</sup> )	RER max	$\dot{V}_Emax$ (l min <sup>-1</sup> )
Able-bodied men	19.6 $\pm$ 0.7	28.4 $\pm$ 5.0	163 $\pm$ 19	1.08 $\pm$ 0.07	73 $\pm$ 17
Able-bodied women	19.6 $\pm$ 0.9	19.0 $\pm$ 2.2	161 $\pm$ 17	1.06 $\pm$ 0.08	41 $\pm$ 5
Poliomyelitis men	19.4 $\pm$ 1.1	24.0 $\pm$ 4.0	165 $\pm$ 14	1.05 $\pm$ 0.05	65 $\pm$ 18
Poliomyelitis women	18.7 $\pm$ 1.1	19.0 $\pm$ 4.1	155 $\pm$ 20	1.01 $\pm$ 0.09	43 $\pm$ 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.*<sup>7</sup>

**Table 3** Mean ( $\pm$  s.d.)  $\dot{V}O_2$  values (ml kg<sup>-1</sup> min<sup>-1</sup> and % $\dot{V}O_{2max}$ ) 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) <sup>a</sup>	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) <sup>b</sup>	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.

<sup>a</sup>Significant difference between men and women of able-bodied group  $P < 0.05$ .

<sup>b</sup>Significant difference between able-bodied and poliomyelitis men  $P < 0.05$ .

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

	Measured $\dot{V}O_{2\text{peak}}$	$\dot{V}O_{2\text{peak}}$ from RPE 13	$\dot{V}O_{2\text{peak}}$ from RPE 15	$\dot{V}O_{2\text{peak}}$ from RPE 17
Able-bodied men	28.4 $\pm$ 5.0	22.5 $\pm$ 10.4	26.6 $\pm$ 9.0	27.4 $\pm$ 8.3
Able-bodied women	19.0 $\pm$ 2.2	20.3 $\pm$ 5.0	20.2 $\pm$ 5.1	19.8 $\pm$ 4.5
Poliomyelitis men	24.0 $\pm$ 4.0	29.0 $\pm$ 10.5	25.9 $\pm$ 7.6	25.9 $\pm$ 6.5
Poliomyelitis women	19.0 $\pm$ 4.1	25.0 $\pm$ 13.8	20.0 $\pm$ 10.3	20.0 $\pm$ 8.6
Able-bodied participants	24.3 $\pm$ 6.2	21.5 $\pm$ 8.3	23.8 $\pm$ 8.0	24.0 $\pm$ 7.7
Poliomyelitis participants	21.4 $\pm$ 4.5	27.1 $\pm$ 11.9	23.1 $\pm$ 9.2	23.1 $\pm$ 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 (bias  $\pm 1.96 \times \text{s.d.}_{\text{diff}}$ ,  $\text{ml kg}^{-1} \text{min}^{-1}$ ) for RPE 13, 15 and 17 ( $-3 \pm 14$ ,  $-1 \pm 10$  and  $0 \pm 8 \text{ml kg}^{-1} \text{min}^{-1}$ , respectively) compared with the poliomyelitis participants ( $6 \pm 19$ ,  $2 \pm 12$  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 sub-maximal 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,<sup>12</sup> 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.<sup>16,17</sup> The equivocal observations may be attributed to the different exercise protocols used in these studies. Lewis *et al.*<sup>17</sup> 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 ACSM<sup>4</sup> 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.<sup>9</sup> 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.<sup>6</sup> 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.*<sup>9</sup> 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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