Estimation of peak oxygen uptake from peak power output in able-bodied and paraplegic individuals

Harran Al-Rahamneh a,*, Roger Eston b,c

a Faculty of Physical Education, University of Jordan, Amman, Jordan
b Exercise for Health and Human Performance, Sansom Institute for Health Research, School of Health Sciences, University of South Australia, Adelaide, SA, Australia
c Sport and Health Sciences, University of Exeter, UK

Received 14 April 2011; accepted 1 May 2012
Available online 17 December 2012

Abstract
This study assessed the accuracy of predicting peak oxygen uptake (VO₂peak) from peak power output (PO_peak) using the equation described by the American College of Sports Medicine (ACSM) during arm-cranking exercise in able-bodied and paraplegic individuals. A total of 13 able-bodied (age: 27.2 ± 4.3 years; mass: 74.5 ± 11.8 kg) and 13 paraplegic men (age: 31.6 ± 5.8 years; mass: 63.7 ± 11.1 kg) volunteered to take part in this study. Participants completed a ramp exercise test (started at 0 W and increased by 15 W/minute) and a graded exercise test (GXT, started at 30 W and increased by 15 W every 2 minutes) designed to assess whether VO₂peak, PO_peak, and peak heart rate (HR_peak) differed between the two exercise tests. PO_peak was significantly higher for the ramp exercise test compared with GXT (p < 0.05). For GXT, no significant difference was noted in the two groups between measured and predicted VO₂peak from PO_peak using the ACSM equation. The 95% limits of agreement between measured and predicted VO₂peak was quite narrow for paraplegic persons (1 ± 6) but not for able-bodied individuals (1 ± 10). In the same way, there was a stronger relationship between measured and predicted VO₂peak for paraplegic persons [intraclass correlation coefficients (ICC) = 0.92] compared with able-bodied participants (ICC = 0.77). For the ramp exercise test, predicted VO₂peak was significantly higher (p < 0.01) than measured VO₂peak for both groups. In conclusion, VO₂peak can be predicted with reasonable accuracy from PO_peak obtained in GXT using the ACSM equation during arm-cranking exercise in able-bodied and paraplegic individuals.

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Keywords: Able-bodied; Arm-cranking exercise; Paraplegic; Peak oxygen uptake; Peak power output

Introduction
Peak oxygen uptake (VO₂peak) is a valuable indicator of cardiorespiratory fitness1,2 and a strong predictor of death in patients with heart disease as well as in all-cause mortalities.3,4 However, measuring VO₂peak is expensive and needs to be done in a laboratory setting, which is not always possible. It is also not feasible to measure VO₂peak for large numbers of people. For these reasons, the American College of Sports Medicine (ACSM) has developed equations to estimate VO₂ during cycling, running/walking on a treadmill as well as during arm-cranking exercise.1

The aim of this study was to assess the validity of estimating VO₂peak from peak power output (PO_peak) during arm-cranking exercise using the equation described by the ACSM (i.e., VO₂ mL/kg/min = 3 × work rate (kg.m/minute)/body mass (kg) + 3.5 mL/kg/minute)1 and whether the exercise protocol [i.e., graded exercise test (GXT) and ramp exercise test] and/or the group (i.e., able-bodied and paraplegic) moderated the findings.
Methods

Participants

A total of 13 able-bodied men [mean ± standard deviation (SD); age: 27.2 ± 4.3 years; height: 173.5 ± 4.9 cm; body mass: 74.5 ± 11.8 kg] and 13 paraplegic men (mean ± SD; age: 31.6 ± 5.8 years; height: 169.7 ± 5.9 cm; body mass: 63.7 ± 11.1 kg) volunteered to take part in the study. Able-bodied participants were healthy, free from illnesses and pre-existing injuries, and physically active (>3 hours per week), but not arm trained (e.g., swimmer). With regard to the paraplegic individuals, seven had flaccid paralysis of the lower limbs as a result of poliomyelitis infection, and six had spinal cord injury with neurological levels at the sixth thoracic vertebra (T6) and below (i.e., T6 to L1). The duration since injury ranged between 4 years and 25 years. The paraplegic participants were physically active (>3 hours 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-crank ergometry used in this study was not a familiar mode of exercise training for both groups. This study was conducted with joint ethics approval from the Ethics Committee at School of Sport and Health Sciences at the University of Exeter and Faculty of Physical Education at the University of Jordan.

Procedures

Each participant (able bodied and paraplegic) completed an arm-cranking GXT (started at 30 W and increased by 15 W every 2 minutes until volitional exhaustion) and a ramp exercise test (started at 0 W and increased by 15 W/minute) designed to establish VO\textsubscript{2peak}. All participants were recommended to avoid moderate and vigorous exercise the day before the exercise test.

All exercise tests were performed on the same 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, adjusted to ±1 W, which is independent of pedal cadence. In accordance with the findings of a previous research, participants were asked to keep the pedal cadence at 60 rpm during all the exercise tests. Expired air was collected through a low resistance Hans Rudolph facemask to allow participants to report their ratings of perceived exertion (RPE). All participants were verbally encouraged to continue as long as possible. On-line respiratory gas analysis occurred every 10 seconds throughout each exercise test via an automatic gas calibrator system (Cortex Metalyzer II, Biophysik, Leipzig, Germany). The system was calibrated before each exercise test using a 3-L syringe for volume calibration and ambient air for gas calibration according to the manufacturer’s guidelines. Heart rate (HR) was recorded continuously using a wireless chest strap telemetry system (Polar Electro T31, Kempele, Finland).

Exercise tests

For the ramp exercise test, after warming up for 3 minutes at 0 W, the exercise test started at 0 W and increased by 1 W every 4 seconds (15 W/minute) until the participants reached volitional exhaustion. 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.

For the GXT, after 3 minutes of warm-up at 0 W, the exercise test started at 30 W and increased by 15 W every 2 minutes until the participants reached volitional exhaustion. The aim of this exercise test was to assess whether peak physical and physiological values observed at the completion of the exercise test differed between the GXT and the ramp exercise test. Participants were asked to report their overall RPE and peripheral RPE during the last 20 seconds of each stage and at the completion of the exercise. If the participant completed 1 minute at least during the last stage, that was considered to be the PO\textsubscript{peak} and the highest mean of VO\textsubscript{2} recorded during the last 20 seconds of each stage was considered as the VO\textsubscript{2peak}.

For both exercise tests, the exercise test was terminated when participants were not able to maintain the required pedal cadence (i.e., if the pedal cadence dropped by 5 rpm for a consecutive 20 seconds from the required pedal cadence) or volitional exhaustion, although they were verbally encouraged to continue the exercise test. In addition, all physiological [i.e., HR, VO\textsubscript{2}, VE, and respiratory exchange ratio (RER)], physical (PO and time) variables were kept out of the participants’ sight during all exercise tests.

Data analysis

A series of two-factor analysis of variances (ANOVA) (test; GXT and ramp exercise test × group; able bodied and paraplegic) was used to assess whether there was a difference in the peak physical and physiological values (i.e., PO\textsubscript{peak}, VO\textsubscript{2peak}, HR\textsubscript{peak}, and RER) observed at the termination of the GXT and the ramp exercise test and between groups. In addition, a three-factor ANOVA (test; GXT and ramp exercise test × method; measured VO\textsubscript{2peak} and predicted VO\textsubscript{2peak} from PO\textsubscript{peak} × group; able bodied and paraplegic) was used to compare measured VO\textsubscript{2peak} and predicted VO\textsubscript{2peak} from PO\textsubscript{peak} using the ACSM equation and whether prediction of VO\textsubscript{2peak} was moderated by the exercise test and/or the participants group. The p value of alpha was set at 0.05. Data were analyzed using SPSS for Windows, PC software, version 16.

An analysis of the limits of agreement (LoA) was also used to assess the agreement between measured VO\textsubscript{2peak} and estimated VO\textsubscript{2peak} from PO\textsubscript{peak} using the ACSM equation. 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 VO2peak scores and the average of the two measurement scores, before performing the LoA analysis. Intraclass correlation coefficients (ICCs) were also calculated using a one-way random model to quantify the relationship between predicted VO2peak and measured VO2peak values.

Results

Descriptive statistics

All physiological, physical, and perceptual values observed at the termination of the GXT and the ramp exercise test for able-bodied and paraplegic individuals are presented in Table 1.

The POpeak achieved during the ramp exercise test was significantly higher compared with the GXT \[F(1,24) = 92.7, \quad p < 0.001\] and significantly higher for the able-bodied participants \[F(1,24) = 16.5, \quad p < 0.001\]. There was no test × group interaction on POpeak \[F(1,24) = 1.5, \quad p > 0.05\]. However, VO2peak was significantly higher during the GXT compared with the ramp exercise test \[F(1,24) = 21.6, \quad p < 0.001\], although there was no difference in VO2peak between groups \[F(1,24) = 1.8, \quad p > 0.05\]. There was no significant test × group interaction on VO2peak \[F(1,24) = 0.0, \quad p > 0.05\].

The HRpeak was higher in the GXT group compared with the ramp exercise test \[F(1,24) = 25.8, \quad p < 0.001\] with no significant difference between able-bodied and paraplegic persons \[F(1,24) = 4.2, \quad p = 0.051\]. There was no significant test × group interaction on HRpeak \[F(1,24) = 0.1, \quad p > 0.05\]. Although the RER values at the termination of the GXT and ramp exercise test were similar \[F(1,24) = 1.1, \quad p > 0.05\], they were higher in the paraplegic group \[F(1,24) = 14.0, \quad p < 0.01\]. There was no test × group interaction on the peak RER values \[F(1,24) = 0.9, \quad p > 0.05\].

Measured VO2peak and predicted VO2peak from the ACSM equation

Measured VO2peak and predicted VO2peak from POpeak using the ACSM equation for able-bodied and paraplegic individuals are presented in Table 2.

Three-factor ANOVA revealed a significant method × test interaction on VO2peak \[F(1,24) = 105.7, \quad p < 0.001\]. Post-hoc analysis showed that the predicted VO2peak from POpeak obtained during the ramp exercise test was significantly higher than the measured VO2peak, irrespective of the group \((p < 0.01)\). There were no significant test × group interaction \[F(1,24) = 0.1, \quad p > 0.05\], no significant method × group interaction \[F(1,24) = 0.0, \quad p > 0.05\], and no significant test × method × group interaction \[F(1,24) = 0.0, \quad p > 0.05\] on VO2peak.

Consistency of VO2peak predictions

LoA and ICC analysis between measured and predicted VO2peak values from POpeak using the ACSM equation are presented in Table 3. LoA between measured and predicted VO2peak for paraplegic individuals during the GXT and the ramp exercise test are presented in Figs. 1 and 2, respectively.

Discussion

Able-bodied participants achieved a significantly higher POpeak compared with their paraplegic counterparts, irrespective of the exercise protocol, and consequently recorded a higher VO2peak (Table 1). This may be attributed to the fact that able-bodied participants were able to use their legs for stabilization and as a fulcrum from which to push.7,8 However, paraplegic individuals reached a higher HRpeak and RER during both exercise tests compared with their able-bodied counterparts. This may be attributable to the higher power output relative to body mass (paraplegic participants

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**Table 1**

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Group</th>
<th>PO (W)</th>
<th>HR (bats/min)</th>
<th>VO2 (mL/kg/min)</th>
<th>RER</th>
<th>RPEe</th>
<th>RPEp</th>
</tr>
</thead>
<tbody>
<tr>
<td>GXT</td>
<td>Able bodied</td>
<td>118 ± 16**</td>
<td>167 ± 14**</td>
<td>34 ± 7**</td>
<td>1.15 ± 0.06*</td>
<td>17.9 ± 1.6</td>
<td>19.7 ± 0.6</td>
</tr>
<tr>
<td></td>
<td>Paraplegic</td>
<td>92 ± 20**</td>
<td>177 ± 15**</td>
<td>31 ± 6**</td>
<td>1.24 ± 0.07</td>
<td>18.5 ± 1.0</td>
<td>19.2 ± 0.9</td>
</tr>
<tr>
<td>Ramp</td>
<td>Able bodied</td>
<td>136 ± 14*</td>
<td>156 ± 14</td>
<td>33 ± 6</td>
<td>1.17 ± 0.05*</td>
<td>17.5 ± 1.5</td>
<td>19.6 ± 0.7</td>
</tr>
<tr>
<td></td>
<td>Paraplegic</td>
<td>106 ± 20</td>
<td>168 ± 16</td>
<td>29 ± 5</td>
<td>1.24 ± 0.07</td>
<td>18.4 ± 1.0</td>
<td>19.4 ± 0.9</td>
</tr>
</tbody>
</table>

*Significant difference between able-bodied and paraplegic individuals \(p < 0.05\).

**Table 2**

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Group</th>
<th>Measured VO2peak</th>
<th>Predicted VO2peak from POpeak</th>
</tr>
</thead>
<tbody>
<tr>
<td>GXT</td>
<td>Able bodied</td>
<td>34 ± 7</td>
<td>33 ± 5</td>
</tr>
<tr>
<td></td>
<td>Paraplegic</td>
<td>31 ± 6</td>
<td>30 ± 5</td>
</tr>
<tr>
<td>Ramp</td>
<td>Able bodied</td>
<td>33 ± 6</td>
<td>38 ± 5*</td>
</tr>
<tr>
<td></td>
<td>Paraplegic</td>
<td>29 ± 5</td>
<td>34 ± 5*</td>
</tr>
</tbody>
</table>

*Significant difference between measured and predicted VO2peak \(p < 0.01\).

ACSM = American College of Sports Medicine; GXT = graded exercise test; POpeak = peak power output; VO2peak = peak oxygen uptake.

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ACSM = American College of Sports Medicine; GXT = graded exercise test; ICC = intraclass correlation coefficient; LoA = limits of agreement; POpeak = peak power output.

Table 3

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Group</th>
<th>LoA between measured and predicted VO2peak (mL/kg/min)</th>
<th>ICC between measured and predicted VO2peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>GXT</td>
<td>Able bodied</td>
<td>1 ± 10</td>
<td>0.77</td>
</tr>
<tr>
<td></td>
<td>Paraplegic</td>
<td>1 ± 6</td>
<td>0.92</td>
</tr>
<tr>
<td>Ramp</td>
<td>Able bodied</td>
<td>−5 ± 7</td>
<td>0.89</td>
</tr>
<tr>
<td></td>
<td>Paraplegic</td>
<td>−5 ± 6</td>
<td>0.92</td>
</tr>
</tbody>
</table>

The higher POpeak values observed during the ramp exercise test, regardless of the group, may be attributed to the more frequent increase in the work rate compared with the GXT. These findings have an important implication in minimizing the effect of local fatigue in termination of the exercise test, and are in accordance with Boone et al., who also observed a higher POpeak during a ramp exercise test compared with a GXT in able-bodied participants during leg cycling.

The significantly higher (p < 0.01) predicted VO2peak from the ramp exercise test for both the able-bodied and paraplegic participants in this study is not surprising. The ACSM equations were derived during steady-state submaximal aerobic exercise. Thus, and as reported by the ACSM, they are only appropriate for predicting the VO2 during steady-state, submaximal aerobic exercise. The high predicted VO2peak from the ramp protocol observed in the current study further confirm that the VO2 is overestimated when it is based on nonsteady-state exercise conditions, when the contribution from anaerobic metabolism is large.

Conclusion

It is concluded that VO2peak can be predicted with reasonable accuracy from POpeak obtained during a GXT using the equation described by the ACSM. The predicted VO2peak values are well within the estimated error associated with the ACSM metabolic equations, which have a standard error of estimate as high as 7%. In this respect, and considering that the 95% confidence interval for predicting VO2peak from similar populations would therefore be ±14%, the predicted values for VO2peak from the GXT in this study are within the predictive error of the equations. The VO2peak can therefore be estimated for able-bodied and paraplegic groups of people because arm-crank ergometry is generally available in gym settings.

References


