ORIGINAL ARTICLE

The validity of predicting peak oxygen uptake from a perceptually guided graded exercise test during arm exercise in paraplegic individuals

HQ Al-Rahamneh and RG Eston

Sport and Health Sciences, College of Life and Environmental Sciences, University of Exeter, Devon, UK

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.

Spinal Cord (2011) **49**, 430–434; doi:10.1038/sc.2010.139; published online 12 October 2010

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.

Correspondence: Professor RG Eston, Sport and Health Sciences, College of Life and Environmental Sciences, St Luke's Campus, University of Exeter, Heavitree road, Exeter, Devon EX1 2LU, UK.

E-mail: r.g.eston@exeter.ac.uk

Received 8 June 2010; revised 1 September 2010; accepted 6 September 2010; published online 12 October 2010

The validity of the perceptually guided exercise test to predict $\dot{V}O_2\text{max}$ 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 $\dot{V}O_2\text{max}$ 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 $\dot{V}O_2\text{peak}$ 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 $\dot{V}O_2$ values elicited during submaximal, perceptually guided exercise tests would provide an acceptable prediction of $\dot{V}O_2\text{peak}$ ($\dot{V}O_2\text{peak}$ 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 $\dot{V}O_2$ values elicited from submaximal, perceptually guided exercise bouts would provide an acceptable prediction of $\dot{V}O_2\text{peak}$ 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 $\dot{V}O_2\text{peak}$. In addition, each participant performed an arm cranking GXT, separated by 48 h from the second perceptually guided exercise test, designed to establish $\dot{V}O_2\text{peak}$. 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 ± 1 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 ($b \cdot min^{-1}$)	$\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	$\dot{V}_E$ ($L \cdot min^{-1}$)	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; $\dot{V}O_2$, 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 $\dot{V}O_{2peak}$ would improve with practice.

Graded exercise test

Each participant completed an arm crank GXT to establish $\dot{V}O_{2peak}$. 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 (PO_{peak}), and the highest mean of $\dot{V}O_2$ recorded during the last 20 s of each stage was considered as the $\dot{V}O_{2peak}$.

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 $\dot{V}O_{2peak}$ (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 $\dot{V}O_{2peak}$ for participant number 3.

used to compare predicted and measured $\dot{V}O_{2peak}$ 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 $\dot{V}O_{2peak}$ for each RPE range. Data were checked for heteroscedasticity by conducting a Pearson correlation analysis between the difference of measured and predicted $\dot{V}O_{2peak}$ 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 (RPE_o) and peripheral RPE (RPE_p)) variables are reported in Table 1.

Measured vs predicted $\dot{V}O_{2peak}$

All measured and predicted $\dot{V}O_{2peak}$ values were normally distributed ($P > 0.05$) using Shapiro–Wilk statistics. Measured and predicted $\dot{V}O_{2peak}$ 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 $\dot{V}O_{2peak}$ 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 $\dot{V}O_{2peak}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) 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

Trial	Measured $\dot{V}O_{2peak}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	Predicted $\dot{V}O_{2peak}$ from RPEs 9–13	Predicted $\dot{V}O_{2peak}$ from RPEs 9–15	Predicted $\dot{V}O_{2peak}$ 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; $\dot{V}O_{2peak}$, 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 $\dot{V}O_{2peak}$ 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 $\sim 4\%$) 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 % $\dot{V}O_{2peak}$ 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 $\dot{V}O_{2peak}$

LoA and intraclass correlation coefficients between measured and predicted $\dot{V}O_{2peak}$ 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 $\dot{V}O_{2peak}$ from the three RPE ranges during both perceptually guided trials

	Measured and predicted $\dot{V}O_{2peak}$ from RPEs 9–13	Measured and predicted $\dot{V}O_{2peak}$ from RPEs 9–15	Measured and predicted $\dot{V}O_{2peak}$ 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; $\dot{V}O_{2peak}$, maximal oxygen uptake.

Figure 3 The 95% limits of agreement (bias $\pm 1.96 \times \text{SD}_{\text{diff}}$, $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) for measured $\dot{V}O_{2peak}$ and predicted $\dot{V}O_{2peak}$ from RPEs 9–13 during the second perceptually guided exercise test.

between measured and predicted $\dot{V}O_{2peak}$ 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 reconverting 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 $\dot{V}O_{2max}$ in healthy, able-bodied individuals during leg cycling.^{7–9}

There were no significant differences between measured and predicted $\dot{V}O_{2peak}$ 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 $\dot{V}O_{2peak}$. 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 $\dot{V}O_{2\max}$ 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.

References

- 1 Åstrand PO, Rodahl K, Dahl HA, Strömme SB. *Textbook of Work Physiology: Physiological Bases of Exercise*. 4th edn. Human Kinetics: Champaign, IL, 2003.
- 2 American college of sports medicine. *ACSM's Guidelines for Exercise Testing and Prescription*. 8th edn. Lippincott, Williams & Wilkins: Philadelphia, 2010.
- 3 Kavanagh T, Mertens DJ, Hamm LF, Beyene J, Kennedy J, Corey P *et al.* Prediction of long-term prognosis in 12169 men referred for cardiac rehabilitation. *Circulation* 2002; **106**: 666–671.
- 4 Borg G. *Borg's Perceived exertion and pain scales*. Human Kinetics: Champaign, IL, 1998.
- 5 Eston RG, Davies BL, Williams JG. Use of perceived effort ratings to control exercise intensity in young healthy adults. *Eur J Appl Physiol* 1987; **56**: 222–224.
- 6 Goosey-Tolfrey V, Lenton J, Goddard J, Oldfield V, Tolfrey K, Eston R. Regulating intensity using perceived exertion in spinal cord-injured participants. *Med Sci Sports Exerc* 2010; **42**: 608–613.
- 7 Eston RG, Lamb KL, Parfitt G, King N. The validity of predicting maximal oxygen uptake from a perceptually-regulated graded exercise test. *Eur J Appl Physiol* 2005; **94**: 221–227.
- 8 Eston RG, Lambreck D, Sheppard K, Parfitt G. Prediction of maximal oxygen uptake in sedentary males from a perceptually regulated, sub-maximal graded exercise test. *J Sports Sci* 2008; **26**: 131–139.
- 9 Eston RG, Faulkner JA, Mason EA, Parfitt G. The validity of predicting maximal oxygen uptake from perceptually regulated graded exercise tests of different durations. *Eur J Appl Physiol* 2006; **97**: 535–541.
- 10 Morris M, Lamb K, Cotterrell D, Buckley J. Prediction of maximal oxygen uptake from the ratings of perceived exertion and heart rate during a perceptually-regulated sub-maximal exercise test in active and sedentary participants. *Eur J Appl Physiol* 2007; **101**: 397–407.
- 11 Morris M, Lamb K, Cotterrell D, Buckley J. Predicting maximal oxygen uptake via a perceptually regulated exercise test (PRET). *J Exerc Sci Fit* 2009; **2**: 122–128.
- 12 Morris M, Lamb KL, Hayton J, Cotterrell D, Buckley J. The validity and reliability of predicting maximal oxygen uptake from a treadmill-based sub-maximal perceptually regulated exercise test. *Eur J Appl Physiol* 2010; **109**: 983–988.
- 13 Collins EG, Gater D, Kiratli J, Butler J, Hanson K, Langbein E. Energy cost of physical activities in persons with spinal cord injury. *Med Sci Sports Exerc* 2010; **42**: 691–700.
- 14 Owen RR, Jones D. Polio residuals clinic: conditioning exercise program. *Orthopedics* 1985; **8**: 882–883.
- 15 Bombardier CH, Richards S, Krause JS, Tulskey D, Tate DG. Symptoms of major depression in people with spinal cord injury: implications for screening. *Arch Phys Med Rehabil* 2004; **85**: 1749–1756.
- 16 Birk TJ. Polio and post-polio syndrome. In: Durstine JL, Moore GE, Painter PL, Roberts SO. (eds). *ACSM's Exercise Management for Persons with Chronic Diseases and Disabilities*, 3rd edn. Human Kinetics: Champaign, IL, 2009, 327–335.
- 17 Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986; **1**: 307–310.
- 18 Coquart JBJ, Eston RG, Grosbois J-M, Lemaire C, Dubart A-E, Luttenbacher D-P, *et al.* Prediction of peak oxygen uptake from age and power output at RPE 15 in obese women. *Eur J Appl Physiol* 2010; **110**: 645–649.
- 19 Eston RG, Brodie DA. Responses to arm and leg ergometry. *Br J Sport Med* 1986; **20**: 4–6.
- 20 McArdle WD, Katch FI, Katch VL. *Exercise physiology energy, nutrition, and human performance*. 6th edn. Lippincott Williams & Wilkins: Baltimore, 2007.