The prediction of maximal oxygen uptake from submaximal ratings of perceived exertion elicited during the multistage fitness test

R C Davies, A V Rowlands, R G Eston

ABSTRACT
The purpose of this study was to assess whether maximal oxygen uptake (VO₂max) could be predicted from submaximal ratings of perceived exertion (RPE) elicited during the multistage fitness test (MFT). Eleven female volunteers completed three maximal exercise tests in random order; the MFT, a simulated MFT on a motorised treadmill and a graded exercise test to volitional exhaustion (GXT), also on a motorised treadmill. RPE values were recorded at the end of each 1 min stage in all three tests. Oxygen consumption (VO₂) was recorded continuously during the treadmill tests. Measured VO₂max values from the GXT and simulated MFT were not significantly different (48.2 and 47.5 ml/kg/min, respectively), but they were significantly higher than VO₂max values predicted by the MFT (41.2 ml/kg/min, p<0.05).

Regression of submaximal RPE values (7–17) elicited from the MFT and VO₂ values predicted by the MFT were extrapolated to RPE 20 to predict VO₂max. The RPE-predicted VO₂max from the MFT (47.5 ml/kg/min) was similar to measured VO₂max. The findings suggest that submaximal RPE values can be used to provide acceptable estimates of VO₂max which are more accurate than the published table values for the MFT. Furthermore, the use of RPE measures in conjunction with the MFT enhances the accuracy of VO₂max prediction by the MFT.
submaximal RPE values elicited during the MFT and that these would enhance the accuracy of the test.

METHODS

Participants

Eleven physically active women (28.1 (SD 7.1) years, 65.8 (SD 5.4) kg, 1.68 (SD 0.05) m), asymptomatic of illness and pre-existing injury, volunteered to take part in the study. Participants were all active members of various local hockey, rowing, football and cricket clubs. The study received institutional ethics approval and written informed consent was obtained from all participants prior to testing.

Procedures

Participants completed three continuous incremental exercise tests to volitional exhaustion in random order. These comprised two laboratory-based sessions and one field assessment, separated by a minimum period of 48 h.13 Prior to testing, participants were familiarised with the equipment and the exercise protocols. Participants were familiarised with Borg’s 6–20 RPE Scale, provided with standardised instructions on how to employ the scale and encouraged to focus on their overall perception of exertion in their responses. Participants were required to work to volitional exhaustion to determine VO2max in all three tests. Standard criteria were used to corroborate the attainment of VO2max.13

Field assessment

The 20 m Multistage Fitness Test (MFT)1 was performed in a sports hall environment in accordance with the test procedure instructions supplied with the CD package. Participants ran in groups and were required to complete as many stages of a 20 m shuttle run as possible until volitional exhaustion. Prior to assessment, participants were asked to listen to a standardised explanation of the test and perform a gentle warm up and stretch. Subjects then ran continuously between 20 m markers, turning in response to an auditory signal emitted from the prerecorded CD. The pace for the first 1 minute level was set at 8 km/h, but accelerated progressively with each subsequent 1 minute level. On reporting an RPE of 15, participants were verbally encouraged until they reached exhaustion and the test was completed. However, if a participant failed to reach the marker before the audio signal on three consecutive shuttles, she was retired from the test.

Heart rate was monitored continuously using the Polar Team System, which is an integrated heart rate monitoring system comprising transmitter belts and an interface unit. The logged heart rate data were subsequently downloaded using the Polar Precision Performance Software (Polar Electro, Kempele, Finland). The RPE scale was displayed on a large clipboard and held directly in front of the participants at one end of the 20 m shuttle. Participants reported an RPE at the end of each exercise level and on completion of the test. No measured VO2 data were recorded during the participants’ performance of the MFT.

Treadmill assessments

Two laboratory-based assessments of VO2max were performed: one graded exercise test (GXT) and one simulation of the MFT. The laboratory-based treadmill simulation of the MFT (Simulated MFT) replicated the pace and the auditory stimulus of the MFT whilst facilitating online pulmonary gas analysis. The treadmill was set at a gradient of 1% and the speed was manipulated by the investigator in time with the auditory signals of the prerecorded CD (level 1 = 8 km/h, level 2 = 9 km/h with an increase of 0.5 km/h for each subsequent level). The GXT also required the subjects to run continuously, but, rather than increasing the running speed, exercise intensity was adjusted by progressively increasing the gradient. The motorised treadmill was set at 9 km/h throughout the test and the gradient was manipulated by the investigator, starting at 0% for the first 1 minute level and increasing by 1% at each subsequent 1 minute level.

The laboratory-based sessions were performed on a motorised treadmill (Woodway, Weil am Rhein, Germany) and respiratory gas analysis was carried out via an online system every 10 s throughout the tests (Cortex MetaLyzer II, Biophysik, Leipzig, Germany). The system was calibrated prior to every test in accordance with manufacturer’s guidelines against known concentrations of cylinder gases (5% oxygen, 15% carbon dioxide) and a 3 l calibration syringe (for flow volume). Heart rates were monitored using a wireless chest strap telemetry system (Polar Electro T31, Kempele, Finland) and recorded continuously via a link to the Cortex gas analysis system. The RPE scale was fixed on the wall in full view of the participants and participants were asked to report an RPE value at the end of each exercise level and on completion of the test. All physiological outputs were concealed from the participants during the testing procedures.

DATA ANALYSIS

Comparison of maximum scores

Measured VO2max values from the two treadmill tests and the table-predicted VO2max value1 for the MFT were compared via a one-way repeated-measures analysis of variance (ANOVA). Mauchly’s test was applied and the degrees of freedom corrected using the Greenhouse-Geisser estimates where sphericity was violated. Post-hoc analyses of significant effects were performed with paired t tests where appropriate. The Bonferroni technique was used to adjust the alpha value to offset the increased risk of type 1 error that occurs when multiple ANOVA comparisons are analysed.

Prediction of VO2max from submaximal MFT RPE

To investigate whether submaximal RPEs from the MFT could be used to predict VO2max, submaximal oxygen uptake values from the table of predicted VO2max values1 were regressed against RPE. Linear regression analysis was performed for each participant on four different submaximal RPE ranges (9–17, 7–17, 9–15 and 11–17). In order to predict VO2max at RPE 20 from the submaximal values, the following equation was employed: VO2max = a + b (RPE 20) (Fig 1).

RPE-predicted VO2max (RPE ranges 9–17, 7–17, 9–15 and 11–17) and measured VO2max values from the GXT were then compared via a one-way repeated-measures ANOVA. Mauchly’s test of sphericity was applied and the Greenhouse-Geisser correction factor was employed where necessary (p<0.05). Post-hoc analysis was performed with paired t tests, with an adjustment made to alpha via the Bonferroni technique.

Reliability analysis

The consistency of the mean VO2max from test to test was quantified in accordance with the recommendations of Lamb et al29 and Bland and Altman.30 Intraclass correlation coefficients (ICCs) were calculated via a two-way mixed-effect model to assess the consistency of the VO2max scores (GXT, MFT and simulated MFT). Similarly, the accuracy of VO2max predictions...
from submaximal RPE:VO₂ relationships, compared with VO₂max measured in the GXT, was assessed by ICCs.

The agreement (difference and random error) between MFT table-predicted VO₂max and measured values from the GXT was quantified using the 95% Limits of Agreement (LoA) technique.7 In addition, the LoA between the submaximal RPE-predicted VO₂max (RPE ranges 9–17, 7–17, 9–15 and 11–17) and measured GXT values were quantified. All LoA statistics were calculated on the basis of the tested assumption that the errors (differences) were normally distributed and heteroscedastic. All recorded data were analysed using the statistical software package SPSS for Windows (version 15) and alpha was set at 0.05.

RESULTS
Comparison of maximum scores
Maximal values for all tests are shown in table 1. A comparison of the mean measured VO₂max values from the GXT and simulated MFT and the mean table-predicted VO₂max values for the MFT revealed significant differences \(F(2, 20) = 15.4, p < 0.01\) (fig 2). Post-hoc paired sample t tests showed no significant differences between the mean measured VO₂max values of the GXT and simulated MFT \(t(10) = 0.8, p > 0.017\). The table-predicted mean VO₂max of the MFT was significantly lower than both the mean measured VO₂max value of the GXT and the mean measured VO₂max value of the simulated MFT \(t(10) = 4.9, p < 0.017\) and \(t(10) = 5.8, p < 0.017\), respectively (fig 2).

Prediction of VO₂max from submaximal MFT RPE
There were no significant differences between submaximal RPE-predicted VO₂max values elicited during the MFT and measured VO₂max from the GXT \(F(1, 12.6) = 1.2, p > 0.05\) (fig 2).

Table 1  Maximal values for oxygen uptake (VO₂max), ratings of perceived exertion (RPEmax), heart rate (HRmax) and respiratory exchange ratio (RERmax) recorded during each of the three maximal tests.

<table>
<thead>
<tr>
<th>Test</th>
<th>VO₂max (ml/kg/min)</th>
<th>RPEmax</th>
<th>HRmax (beats/min)</th>
<th>RERmax</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFT</td>
<td>41.2 (7.7)</td>
<td>18.0 (1.2)</td>
<td>187 (7.4)</td>
<td>n/a</td>
</tr>
<tr>
<td>Simulated MFT</td>
<td>47.5 (10.0)</td>
<td>19.4 (0.9)</td>
<td>187 (8.1)</td>
<td>1.06 (0.1)</td>
</tr>
<tr>
<td>GXT</td>
<td>48.2 (9.7)</td>
<td>19.5 (0.5)</td>
<td>187 (10.1)</td>
<td>1.07 (0.1)</td>
</tr>
</tbody>
</table>

Values are mean (SD).

GXT, graded exercise test; MFT, multistage fitness test.

Figure 1  An example of VO₂max prediction using submaximal RPE 9–17 data obtained during the multistage fitness test.

Figure 2  VO₂max (mean (SEM)) values from the MFT, simulated MFT, GXT and submaximal RPE prediction from the MFT. * Significant difference between MFT table-predicted VO₂max and all other VO₂max values. GXT, graded exercise test; MFT, multistage fitness test; RPE, rating of perceived exertion.

Reliability analysis
Comparison of maximum scores
Measures of the consistency of the mean VO₂max of the GXT and simulated MFT were high (ICC = 0.98, p < 0.001) and superior to the consistency of the GXT and MFT (ICC = 0.93, p < 0.001) and the consistency of the simulated MFT and MFT (ICC = 0.92, p < 0.001). The ICCs between all four of the RPE range-predicted VO₂max values and measured VO₂max from the GXT were significant (ICC > 0.91, p < 0.05) (table 2). RPE range 7–17 gave the most reliable prediction of VO₂max (ICC 0.95, p < 0.05).

Limits of Agreement analysis revealed that the MFT showed the greatest mean difference between predicted and measured VO₂max values (−6.4 ml/kg/min). The RPE range 7–17 gave the smallest mean difference (−0.6 ml/kg/min). The 95% Limits of Agreement were similar for all estimates of VO₂max (±8.5–11.7 ml/kg/min) although narrowest for the table-predicted values (±8.5 ml/kg/min) (table 2).

DISCUSSION
The purpose of this study was to investigate the efficacy of predicting VO₂max from submaximal RPE values elicited during the multistage fitness test (MFT).1 Comparison of the measured VO₂max values from two laboratory tests and the values predicted by the MFT indicated that the MFT underestimated VO₂max in this group of healthy, physically active women. These findings corroborate those of previous research8–12 in reporting an underestimation of VO₂max by the MFT. However, it was established that submaximal RPE values elicited during
the MFT could be used to improve the accuracy and reliability of the predictions of VO₂max.

The prediction of VO₂max in this study was based on individual submaximal RPE responses elicited during the MFT. The findings revealed no significant differences in the perceptual ranges (RPE 9–17, 7–17, 9–15, 11–17) ability to predict maximal values. Narrowing the perceptual range by excluding markers of “extremely light” and “very hard” (RPE 9–15) did not impact significantly on the accuracy of the prediction. Deciding which perceptual range should be used for predicting VO₂max may best be determined by the characteristics of the subjects being tested and the need for accuracy in the test. Whist this study used healthy, active women, a more sedentary or clinical population might benefit from a protocol that avoids the use of RPE 17, particularly as working to an exertion level equivalent to RPE 17 may be associated with a negative effect in a more sedentary population.

The strong relationship between RPE and VO₂ which enabled VO₂max to be predicted from submaximal exercise in the MFT may be the result of a direct or an indirect association. Oxygen uptake is one of many cardiopulmonary variables that increase with rises in exercise intensity. It has been suggested that afferent feedback from these and other peripheral factors, such as the sensation of muscle soreness resulting from exercise-induced muscle damage, antecedent fatigue, carbohydrate availability, and blood lactate levels, is integrated to generate perception of exertion during physical activity.

However, the cluster of cardiopulmonary and peripheral cues may simply serve to enhance a feedforward mechanism which ensures the body does not exceed its physical limits. It has been proposed that perceived exertion may be set in an anticipatory manner from the start of exercise according to the perceived distance or duration of the task in a process known as teleoanticipation. The majority of participants in this study had prior knowledge of the MFT. They were aware of the temporal and incremental nature of the tests and that they would exercise to volitional exhaustion. Several studies have investigated the scalar relationship between RPE and exercise duration. More recently Noakes and Eston et al based their work on the premise that RPE is reported as a proportion of the time to volitional exhaustion. Hence individual RPE responses for these subjects could have been regulated as the test progressed within an anticipated personal time-frame. Individual awareness of the potential time to end task would have enabled a protective reserve capacity to be held.

Familiarity with the MFT or with the RPE scale may have influenced the RPE reported. The reliability of RPE improves with protocol familiarity. In the present study the 95% LoA for the VO₂max values predicted from submaximal RPE ranged from ±9.2 ml/kg/min to ±11.7 ml/kg/min. These values are similar to those reported by Eston et al when VO₂max was predicted from submaximal perceptually regulated exercise bouts (±7.3 ml/kg/min to ±11.3 ml/kg/min), which were observed to improve with practice (±5.8 ml/kg/min to ±8.4 ml/kg/min). Familiarity with the use of RPE in the MFT might provide estimates of VO₂max with LoA that could be as narrow as or better than those provided by the MFT table in this study (±5.5 ml/kg/min).

In conclusion, the data revealed that the MFT significantly underpredicted VO₂max in this group of healthy, active women. However, submaximal RPE values elicited during the MFT provided accurate and reliable estimates of VO₂max. These findings demonstrate that the accuracy of the MFT can be enhanced by the simple incorporation of measures of RPE during testing procedures. The findings may also have implications where using the MFT in its current maximal form is inappropriate. Further investigations are justified to explore the potential of this method whilst accounting for the effects of familiarisation, gender, age, exercise experience and fitness along with the influence of psychological factors. In addition, the efficacy of submaximal RPE estimation procedures to predict maximal functional capacity in sedentary and clinical populations should also be considered.

Competing interests: None.

REFERENCES


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doi: 10.1136/bjsm.2007.043810

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