Validation of the 12-Minute Cycle Ergometer Test Using a Higher Resistance Setting

Paul M. Vanderburgh and Ronald E. DeMeersman

The 12-Minute Stationary Cycle Ergometer Test (12MCET) has been developed and validated as an accurate VO\textsubscript{2}\text{peak} prediction test particularly for the injured (7). Prediction is based on body weight and total work done in 12 min at a resistance setting of 2.5 kp (men) and 2.0 kp (women) on the Monark cycle ergometer. In the development of the 12MCET a small number of subjects stated a preference for a higher resistance setting than 2.5 kp. The purpose of this study was to validate the use of the 12MCET with a resistance setting of 3.0 kp for a sample of 30 college-age men. When applied to the 12MCET, use of the 3.0 kp resistance setting overpredicted actual VO\textsubscript{2}\text{peak} by a mean of 175 ml \cdot min\textsuperscript{-1} (p = .02). We concluded that the use of a 3.0 kp resistance setting for the 12MCET is inappropriate and that any resistance setting other than that prescribed should not be used without proper validation.

Peak aerobic power assessment is an important component of health-related physical fitness evaluation. Many predictive tests have been developed and validated against open-circuit spirometry, the criterion assessment method. One such test, the 12-Minute Stationary Cycle Ergometer Test (12MCET), was developed and validated specifically for use with college-age men and women who needed accurate peak aerobic power assessment but, because of injury, surgery, or other conditions, could not tolerate the high joint stress of walking/running or the high pedal torques of a graded exercise test (GXT) on a cycle ergometer (7). This test predicts VO\textsubscript{2}\text{peak} based on the total work done in 12 min (kpm in a maximal effort format), or TW\text{12}, and body mass: \( R = .97, \text{SEE} = 200.7 \text{ ml \cdot min}\textsuperscript{-1}, \) on the Monark cycle ergometer for college-age men and women.

For the 12MCET, men and women used a resistance setting of 2.5 and 2.0 kp, respectively. These settings were chosen based on Vanderburgh and DeMeersman’s previous investigation (8) which suggested that the 2.5 kp setting yielded high prediction quality for college-age men. Furthermore, men, who

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generally have a higher body mass than women, are capable of pedaling against a higher load. Therefore the women’s load was selected to be less than the men’s.

For the past 3 years, the 12MCET has been used to assess the fitness levels of over 500 service academy cadets who, because of injury or surgery, would otherwise be untestable in a maximal effort format. Use of the 12MCET is certainly not limited to the injured; it has the same applicability to injury-free subjects.

Perhaps one limitation of the 12MCET is that of one resistance setting: 2.5 and 2.0 kp for men and women, respectively. In the sample of subjects used to develop the original 12MCET, some of the men who had particularly high fitness level/body weight combinations stated a preference for a higher resistance setting. One might expect the higher resistance setting to result in a proportionately lower total number of pedal revolutions in the 12MCET so that TW12 would be the same. The classic force–velocity–power curve of skeletal muscle, however, suggests that there exists an optimal contraction rate for skeletal muscle that produces optimal power (2). In cycle ergometry, this means that pedal rate is probably not linearly related to resistance setting when maximizing sustainable aerobic power.

Furthermore, increasing the resistance setting could alter the prediction quality of the 12MCET due to an increased contribution of leg strength to overcome the higher torque. In other words, at a higher resistance setting, leg strength could account for additional variance in VO2peak, above and beyond that accounted for by body weight and TW12. Given this and the fact that the 12MCET demonstrated high external validity (7) at a 2.5 and 2.0 kp setting for men and women, respectively, cross validation of a sample of men riding the 12MCET at a higher resistance setting was warranted.

The purpose of this study was to cross validate the 12MCET on a sample of 30 college-age men who rode the 12MCET at a resistance setting of 3.0 kp. We chose this setting because several riders from the original 12MCET investigation (8) preferred a higher resistance setting.

Methods

Subjects

Subjects were 30 male service academy cadets (validation, or VAL, group) from the same population as those used to develop the 12MCET. As shown in Table 1, we compared subject descriptives of the VAL group with those of the 30 men used to develop the 12MCET (30 women were also subjects). The two samples were similar in mean body weight and age, suggesting that the VAL group was an appropriate cross validation sample for this investigation.

All subjects were injury-free, a necessary condition for tolerating the high pedal torques of graded exercise tests (GXT) for open-circuit spirometry (actual VO2peak assessment) on the cycle ergometer. That the 12MCET can be applied to injured subjects requires only that they be capable of pedaling at their maximal sustainable aerobic potential at the low pedal torques required of the 12MCET. As stated earlier, we have found over 500 such subjects, especially in the rigorous
Table 1
Subject Descriptives

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<tr>
<th></th>
<th>2.5 kp group</th>
<th>3.0 kp group</th>
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<tbody>
<tr>
<td>(12MCET sample)</td>
<td>(VAL sample)</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>20.07</td>
<td>20.13</td>
</tr>
<tr>
<td></td>
<td>1.39</td>
<td>1.55</td>
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<tr>
<td>Weight (kg)</td>
<td>81.77</td>
<td>83.13</td>
</tr>
<tr>
<td></td>
<td>12.99</td>
<td>11.26</td>
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<tr>
<td>VO2peak (ml · min⁻¹)</td>
<td>3,942.7</td>
<td>4,034.3</td>
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<tr>
<td></td>
<td>542.7</td>
<td>486.6</td>
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<tr>
<td>VO2peak (ml · kg⁻¹ · min⁻¹)</td>
<td>48.79</td>
<td>48.79</td>
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<tr>
<td></td>
<td>7.51</td>
<td>5.03</td>
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<tr>
<td>TW12 (kpm)</td>
<td>17,633</td>
<td>18,912</td>
</tr>
<tr>
<td></td>
<td>2,320</td>
<td>2,349</td>
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training environment of the service academy. We conjectured that the 12MCET, though developed out of necessity with injury-free subjects, could be applied to certain injured subjects with no loss of validity.

Procedures

Subject testing consisted of two assessments on two separate days. Day 1 testing consisted of VO2peak assessment via open-circuit spirometry on the cycle ergometer. On Day 2 subjects rode the 12MCET at a resistance setting of 3.0 kp. The 48-hr interval between testing days allowed complete recovery from the VO2peak assessment and minimized the possibility of any change in fitness level.

We designed a unique cycle GXT for VO2peak assessment for use with the Monark 818E stationary cycle ergometer and the Beckman Sensormedics Metabolic Measurement Cart (MMC). Its unique feature was that it used body mass and a self-reported fitness estimate to predict the endpoint (external power of the last stage) of the GXT. This was only for our convenience; this method allowed the time of testing to be reduced from those of standard GXTs, especially for fit subjects. Subjects were weighed (Healthometer scale calibrated twice monthly with known weights and zeroed before each weighing) and were queried about their fitness level. We did this by asking them for an estimate of their current 2-mile run time performance. As all subjects were required, as part of their service academy fitness testing, to take the Two-Mile Run Test twice annually for grade, we could assume that they had a reasonable “feel” for their fitness status at the time of the GXT.

We used the 2-mile run estimate and body mass to estimate each subject’s endpoint for the cycle GXT by using the equations of Storer et al. (6) and Mello et al. (4). With this estimate, we could design a 12-min GXT for each subject based on his fitness level or body mass. This proved time-efficient, as other
standard protocols would have taken over 20 min for some of the more fit subjects. The relative work loads and times for each stage of the GXT are shown in Table 2. This protocol conformed to the standards prescribed by Pollock et al. (5).

We calibrated the MMC before each test in accordance with the manufacturer’s guidelines, using a known rate and quantity of air for the flowmeter, via a 1-L syringe, and known concentrations of O₂, CO₂, and N₂. The criteria for \( \dot{V}O_2 \) peak attainment were any two of the following three: heart rate within 15 beats of age-predicted maximum heart rate, a plateau of \( \dot{V}O_2 \) with an increase in work rate, and RQ \( \geq 1.1 \) (3).

The 12MCET test for each subject took place on Day 2. Subjects were weighed again (this weight was the recorded body mass for the regression model) and were asked to warm up on the Monark 818E cycle ergometer at a work rate of their choosing for 3 min. Subjects stopped pedaling after the warm-up and we reset the cycle ergometer’s digital pedal revolution counter to zero and the resistance setting to 3.0 kp. We then instructed subjects, on the command “go,” to pedal for 12 min as hard as possible. To promote maximal sustainable effort, we provided verbal encouragement, never abusive or loud, throughout the test. At 12 min, we recorded total pedal revolutions, from which we could calculate total work in 12 min (TW12) based on the 6-m per pedal revolution belt constant (1).

**Data Analysis**

All data analysis was done via the SPSS-Student personal computer software package. For each subject we entered body weight and TW12 into the 12MCET equation (7) to predict \( \dot{V}O_2 \) peak:

\[
\dot{V}O_2 \text{peak (ml · min}^{-1}) = .186(\text{TW12}) + 10.69(\text{BWkg}) - 197
\]
We then computed a Pearson product moment correlation and a standard error of the estimate (SEE) between predicted and actual VO₂peak values. As it was still possible, even with a high correlation and low SEE, that the means of actual and predicted VO₂peak were significantly different, we also conducted a paired t test.

**Results and Discussion**

The Pearson product moment correlation was calculated between actual and predicted VO₂peak for the VAL group as applied to the 12MCET: \( r = .85; \text{SEE} = 263.3 \text{ ml} \cdot \text{min}^{-1} \). This high correlation and relatively low SEE suggested that the relationship between actual and predicted values was close to linear. The paired t test between their mean values, however, revealed a significant difference of 175 ml \( \cdot \text{min}^{-1} \) \((p = .02)\). This suggested that the use of the 3.0 kp setting for men with the 12MCET overpredicted VO₂peak.

Applying the VAL group’s 3.0 kp resistance setting to the 12MCET resulted in a mean overprediction error of 175 ml \( \cdot \text{min}^{-1} \) \((p = .02)\). This systematic error, though relatively small, is almost as large as the SEE of the 12MCET (200.7 ml \( \cdot \text{min}^{-1} \)). Use of a 3.0 kp resistance setting, then, is arguably inappropriate for the 12MCET.

This overprediction is likely due to the VAL group having a significantly higher mean TW12 than the 30 male subjects from the original 12MCET (18,912 vs. 17,633 kpm, \( p = .04 \)) despite being similar in fitness level and body weight (Table 1). This was likely due to the optimal contraction speed for optimizing power in skeletal muscle, as mentioned previously, and possibly an increased contribution of leg strength (which was not accounted for) rather than greater aerobic capacity at the 3.0 kp resistance setting.

We then investigated further the applicability of the 12MCET to large/fit subjects. Based on our observations of several hundred subjects who have taken the test, we felt that a pedal rate of approximately 130 rpm was the upper limit of biomechanical capability. Although we have never seen subjects pedal beyond this point in the 12MCET, we theorized that pedal rates in excess of 130 rpm prevent subjects from applying sufficient torque throughout the pedal range of motion. They would, then, be pedaling at a rate less than their maximal sustainable aerobic potential. This would lead to an underestimation of their VO₂peak.

Using the 12MCET equation and this upper limit of 130 rpm pedal rate (or a TW12 of 23,400 kpm at a resistance setting of 2.5 kp) we examined theoretical upper limits for actual VO₂peak at different body weights. This procedure would help us identify the largest and most fit subject that could be tested on the 12MCET. For example, a 100-kg male could have a true VO₂peak of up to 5,224 ml \( \cdot \text{min}^{-1} \) and still be testable on the 12MCET, based on our criteria. Beyond this fitness level, he would have to pedal at a rate greater than 130 rpm. Similarly, an 80-kg male could have a true VO₂peak of 5,010 ml \( \cdot \text{min}^{-1} \) and still be testable. These theoretical subjects represent very fit men.

At the opposite end of the fitness level and body weight continuum, the 12MCET seemed efficacious for even unfit and light male subjects. For those as light as 60 kg with a true VO₂peak of as little as 2,700 ml \( \cdot \text{min}^{-1} \), a theoretical
pedal rate of 67 rpm would be achieved, an arguably acceptable rate. These data suggest that the 12MCET, with its resistance setting of 2.5 kp for men, accommodates a wide range of fitness levels and body weights.

Conclusion

In this investigation, selection of a 3.0 kp setting led to a mean overprediction error of \( \dot{V}O_2 \text{peak} \) of 175 ml \( \cdot \) min\(^{-1} \) in a cross validation sample of 30 college-age male subjects. We concluded that this higher resistance setting for the 12MCET is inappropriate. Settings other than those prescribed by the 12MCET should be cross validated before being universally used. Furthermore, theoretical analysis indicates that the 12MCET accommodates a wide range of fitness level and body weight combinations of college-age men, suggesting that other resistance settings are unnecessary.

References