Reliability and validity of physiological data obtained within a cycle-run transition test in age-group triathletes

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Abstract

This study examined the validity and reliability of a sequential “Run-Bike-Run” test (RBR) in age-group triathletes. Eight Olympic distance (OD) specialists (age 30.0 ± 2.0 years, mass 75.6 ± 1.6 kg, run \( V_{O2max} \) 63.8 ± 1.9 ml·kg\(^{-1}\)·min\(^{-1}\), cycle \( V_{O2peak} \) 56.7 ± 5.1 ml·kg\(^{-1}\)·min\(^{-1}\)) performed four trials over 10 days. Trial 1 (TRV \( O_2max \)) was an incremental treadmill running test. Trials 2 and 3 (RBR1 and RBR2) involved: 1) a 7-min run at 15 km·h\(^{-1} \) \( (R_1) \) plus a 1-min transition to 2) cycling to fatigue \( (2 \ W·kg^{-1} \) body mass then 30 W each 3 min); 3) 10-min cycling at 3 W·kg\(^{-1} \) \( (B_{submax}) \); another 1-min transition and 4) a second 7-min run at 15 km·h\(^{-1} \) \( (R_2) \). Trial 4 (TT) was a 30-min cycle - 20-min run time trial. No significant differences in absolute oxygen uptake \( (V_O2) \), heart rate \( (HR) \), or blood lactate concentration \( ([BLA]) \) were evidenced between RBR1 and RBR2. For all measured physiological variables, the limits of agreement were similar, and the mean differences were physiologically unimportant, between trials. Low levels of test-retest error \( (i.e. \text{ICC} < 0.8, \text{CV} < 10\%) \) were observed for most \( (\text{logged}) \) measurements. However \( [BLA] \) post \( R_1 \) \( (\text{ICC} 0.87, \text{CV} 25.1\% \) and \( [BLA] \) post \( B_{submax} \) \( (\text{ICC} 0.99, \text{CV} 16.31\%) \) and \( [BLA] \) post \( R_2 \) \( (\text{ICC} 0.51, \text{CV} 22.9\%) \) were least reliable. These error ranges may help coaches detect real changes in training status over time. Moreover, RBR test variables can be used to predict discipline specific and overall TT performance. Cycle \( V_{O2peak} \), cycle peak power output, and the change between \( R_1 \) and \( R_2 \) \( (deltaR_{1-R2}) \) in \( [BLA] \) were most highly related to overall TT distance \( (r = 0.89, p < 0.01; r = 0.94, p < 0.02; r = 0.86, p < 0.05, \text{respectively}) \). The percentage of \( TR \ V_{O2max} \) at 15 km·h\(^{-1} \), and \( deltaR_{1-R2} \) HR, were also related to run TT distance \( (r = -0.83 \text{ and } 0.86, \text{both } p < 0.05) \). 

Key words: Multi-discipline, reproducibility, time-trial, test, adaptation.

Introduction

Coaches require a reasonable degree of confidence that the changes in test measures that are obtained by their athlete(s) are due to training adaptations rather than due to measurement error (Atkinson and Nevill, 1998). The scores that are obtained on a laboratory test must also adequately reflect the needs of the sport. Therefore, the physiological measures that are obtained within any “sport specific test” should be shown to be reliable, and to be relevant to performance in that sport.

Although triathlon involves a sequential swim, cycle and run; swim test results have been shown not to be significantly related to triathlon performance (Millet et al., 2003). In contrast, physiological data obtained from both isolated (maximal incremental and submaximal) cycle or run tests have successfully predicted triathlete race or time trial performance (Hue, 2003; Schabort et al., 2000; Zhou et al., 1997). Schabort et al. (2000), for example, found cycle and run blood lactate concentration \( ([BLA]) \) at 4 W·kg\(^{-1} \) and 15 km·h\(^{-1} \), respectively; cycle peak oxygen uptake \( (V_{O2peak}) \); and peak treadmill running velocity \( (TRV_{max}) \) to be the best predictors of Olympic distance (OD) (1.5 km swim, 40 km cycle, 10 km run) triathlon performance in South African National Squad triathletes. End cycle \( [BLA] \) and total distance run within a 30-min cycle–20-min run combined laboratory time trial were also shown to account for 93% of the variation in draft-legal OD triathlon finishing times of Elites (Hue, 2003). However, time trials do not provide the scientist or coach with information regarding peak workload or the anaerobic threshold – both of which measures can be important for training prescription and analysis.

As adaptation to the cycle-run transition has been shown to affect both triathlon run pacing and, therefore, finishing position (Vleck et al., 2008), assessment of the ability to run after cycling (Millet and Vleck, 2000) is also an important and sports specific component of the analysis of a triathlete (Vleck and Alves, 2011). Millet et al. (Millet et al., 2003; Millet and Bentley, 2004) were the first to assess the relationship between triathlete race performance and physiological variables obtained from a sequential, laboratory-based, “run-bike-run” (RBR) test. The latter comprises submaximal running, maximal and then submaximal cycling, followed by an additional submaximal running bout. The test is unique in so far as it allows both for important physiological variables that are normally obtained from isolated tests (such as cycle \( V_{O2peak} \) and peak power output \( [Schabort et al., 2000]) \) to be determined, and measurement of the extent to which the athlete adapts to a cycle-run transition (T2). As both running bouts during the sequential RBR are conducted at the same speed, the first run \( (R_1) \) of the test acts as a control to which physiological data from the second, post-
cycle, run (R2) (such as running economy) can be compared, and this allows for the efficiency of running after cycling to be established.

Both cycle VO2max (r = -0.80, p < 0.001) and cycle peak power output (Wpeak) (r = -0.85, p < 0.001), obtained within the Millet RBR test, have been found to be significantly related to the OD performance times of French National Squad triathletes. However, certain aspects of the test are open to modification. Firstly, both runs are conducted at a speed corresponding to the subject’s current personal best OD triathlon run time, although set workloads are usually used to measure running economy (Saunders et al., 2004a; 2004b). Secondly, the protocol that is used to determine cycle VO2max and Wpeak within the incremental “bike” of the RBR (i.e. 3-minute increments of 70 W from an initial workload of 70 W until 280 W, and then 35 W increases every 2 minutes until exhaustion) has not been validated for that purpose. Thirdly, the submaximal cycle is conducted at 80% of the Wpeak that was arrived at within the preceding incremental cycle section. The physiological responses to cycling at said workload has not yet been specifically related to cycling and overall triathlon performance, as has power output standardised to body mass (Schabort et al., 2000). Power output standardised to body mass may in itself be an easier measure than power at 80% Wpeak to use for tracking changes in cycling economy over time.

Moreover, although prior cycling appears to have more of an adverse affect on subsequent running in middle-level, “age-group”, triathletes than in elite triathletes (Millet et al., 2001), almost all of the cycle-run transition test research to date (see Vleck and Alves [2011] for bibliography) has involved National Squad athletes.

The focus of this study, therefore, was to investigate the reliability and validity of a version of the Millet laboratory-based incremental “Run-Bike-Run” (RBR) transition test (Bentley et al., 2005), that has been modified so as to address some of the aforesaid limitations, in well-trained age-group male triathletes. The modified RBR test incorporates aspects of both Millet et al.’s and Schabort et al.’s approach (Millet et al., 2000; 2001; 2003; Millet and Bentley, 2004; Schabort et al., 2000). It still involves submaximal running, maximal then submaximal cycling, and an additional submaximal running bout. However, both runs are conducted at a standardised speed of 15 km·h⁻¹ - the [BLA] after which was shown by Schabort et al. (2000) to be related to OD performance time. Moreover, the protocol of the incremental cycle section of the RBR has been amended to one that has been previously validated for the determination of Wpeak in cyclists (Bentley and McNaughton, 2003) (i.e. to one with 30 W increments every 3 min). Additionally, the submaximal cycle section has also been standardised relative to body mass - but to 3 W·kg⁻¹ rather than the 4 W·kg⁻¹ the [BLA] after which was demonstrated to be related to OD performance (Schabort et al., 2000) because 4 W·kg⁻¹ may prove too demanding for age-group athletes.

Methods

The experiment involved four trials over 10-days, each separated by at least 48 h. The testing comprised: (1) an incremental treadmill running test to exhaustion (TRVO2max); (2) and (3) the “Run-Bike-Run” trial (termed RBR), on its first occasion and, when repeated, RBR₂; and 4) a laboratory based 30-minute cycle–20-min run distance trial (TT). TRVO2max was completed first and the remaining tests were performed in randomised counterbalanced order.

Subjects

Eight well-trained male age-group triathletes specialising in OD competition gave their written informed consent to participate in the experiment. All the subjects were both in active pre-competition training (of approximately 12 h·wk⁻¹), and were familiarised with the exercise test procedures prior to participation in the study.

During the 48 h prior to each test the athletes completed only low-volume, low-intensity training; and standardised said training as well as their food and fluid intake. They were further encouraged to drink 150-200 ml water every 20 minutes of the 2 hours prior to each test start. All the tests were conducted at the same time of day and under the same environmental conditions. Body mass was assessed immediately prior and post-test to assess whether any significant change in hydration levels had taken place.

The study was conducted in accordance with the 1975 Declaration of Helsinki and approved by the local Institutional Research Ethics Committee.

Procedures

Incremental running test (TRVO2max)

The TRVO2max was conducted on a Powerjog treadmill (Powerjog, UK) and was preceded by a 5-minute warm up at 8 km·h⁻¹ and 1% gradient (Jones and Dout, 1996), and involved increments of 1 km·h⁻¹ every 60 s until the athlete could not maintain the required speed. Breath-by-breath analysis of expired air was conducted throughout using a portable gas analysis system (K4B², Cosmed, Rome, Italy), that had been calibrated immediately beforehand according to the manufacturers’ instructions. Heart rate (HR) was measured every second using a heart rate monitor integrated with the calorimetry system.

Peak running speed (TRVmax) was recorded as the highest speed completed over 60 s. Treadmill (TR) HRmax (b·min⁻¹) was defined as the highest consecutive 5 s mean during the test. Maximum run oxygen uptake (TRVO2max) was determined as the highest 30-s mean value obtained during the incremental run test, when at least two of the criteria of an oxygen uptake plateau (defined as a failure to maintain the slope of the individual specific work-rate-VO2 relationship), 85% of age-related HRmax, a respiratory exchange ratio of above 1.15, and/or a rating of perceived exertion of over 18 on the Borg (1982) scale, had been achieved (Midgeley et al., 2007). The ventilatory threshold (VT) was determined from VE, VE·VCO2 and VE·VO2 data averaged over 30-s intervals, by two experienced observers working independently (Davis et al., 1980). The values obtained differed from each other by less than 1%.
Run-bike-run (RBR) trials
On two other occasions (RBR1 and RBR2) each subject performed a sequential run-bike-run trial (Figure 1) that comprised: 1) submaximal running (R1); 2) a maximal incremental cycle test (B\(\dot{V}O_2\)peak); 3) submaximal (Bsub) cycling; and 4) an additional submaximal run (R2). The subjects completed a standardised warm up prior to the test that involved 5 minutes of running at <10 km·h\(^{-1}\) and 5 minutes of cycling at 150 W, followed by light stretching.

R1 of RBR involved a 7-minute run at 15 km·h\(^{-1}\) and 1% gradient, in conjunction with breath-by-breath gas analysis. With the gas analyser mask still attached, and within 1 minute, each subject dismounted the treadmill, changed into cycling shoes, and mounted the cycle ergometer (Kingcycle Ltd., High Wycombe, Buckinghamshire, UK). The subject then performed 5 minutes of unloaded cycling before part 2 of the test (i.e. B\(\dot{V}O_2\)peak). B\(\dot{V}O_2\)peak commenced with a 3-minute workload of 2 W·kg\(^{-1}\). The subject was then required to increase power output by 30 W every 3 minutes until voluntary exhaustion (Bentley and McNaughton, 2003). Pedalling frequency was maintained at \(\sim 90\) rev·min\(^{-1}\) (Lucia et al., 2001). The subject then performed 2 minutes of unloaded cycling before part 3 of the test (Bsubmax). Bsubmax involved 10 minutes of cycling at 90 rev·min\(^{-1}\) and 3 W·kg\(^{-1}\). Within 60 s of completion of Bsubmax, the subject dismounted the cycle ergometer, changed back into running shoes and mounted the treadmill (which was rolling at 15 km·h\(^{-1}\) and 1% gradient), ready to start the final test stage. This was a second 7-minute submaximal running bout (R2) at 15 km·h\(^{-1}\).

Fingertip blood lactate concentration ([BLA]) was measured in duplicate immediately before, and within 30 s of completion of, each of the four sub-sections of RBR (i.e. R1, B\(\dot{V}O_2\)peak, Bsubmax and R2, as illustrated in Figure 1), using a Lactate Pro portable lactate analyser (Lactate Pro, Arkray Shiga, Japan) (Pyne et al., 2000). The subjects were reminded of this by a protocol diagram (Figure 1), in clear view of both ergometers. During B\(\dot{V}O_2\)peak, \(\dot{V}O_2\)peak, HRmax (b·min\(^{-1}\)) and the VT were calculated as previously described (see Incremental running test). Peak power output (W\(_{\text{peak}}\)) (W) for B\(\dot{V}O_2\) was calculated using the equation of Hawley and Noakes (1992): 

\[
W_{\text{peak}} = W_t + (t/180 \times 30 W)
\]

where \(W_t\) = power output (W) of last complete stage; \(t\) = duration (s) of final non-complete stage; 180 = workload duration (s); and 30 = workload increment (W).

During Bsubmax, cycle economy (B\(_{\text{EC}}\)) was measured as the ratio of the power output (W) to \(\dot{V}O_2\) (l·min\(^{-1}\)) consumed (Millet et al., 2004). In the last 60 s of R1 and R2, \(\dot{V}O_2\) (ml·kg\(^{-1}\)·min\(^{-1}\)) was averaged and economy (EC\(_{\text{Run}}\)) calculated (\(\dot{V}O_2\) / km·h\(^{-1}\)) (di Prampero, 1986).

Cycle-run time trial (TT)
The athletes also completed a laboratory cycling-running time trial (TT) (Hue, 2003). Beforehand, they performed a 5–10 minute submaximal cycle-run warm-up. They were then allowed 60 s to “get up to speed”, i.e. a rolling start on the cycle ergometer, before the TT started. The cycle section of the test (B-TT) involved cycling as hard as possible for 30 minutes, without doing a sprint finish (Suriano and Bishop, 2010). The subjects then had 1 min-
ute to “transition” (i.e. change into running shoes and then move) to the treadmill, which was rolling at 15 km·h⁻¹ and 1% gradient. The run section of TT (R-TT) required the subject to run as far as possible in 20 minutes. The athlete was free to change the treadmill speed throughout.

The distance (m) covered within B-TT, R-TT, as well as total (B-R) TT distance was monitored. Fingertip [BLA] was also assessed, in duplicate, pre B-TT, within the last minute of B-TT, pre R-TT, and immediately on completion of B-R TT.

### Statistical analyses

Data are presented as mean ± s. To allow for easier interpretation, various reliability statistics were used (Atkinson and Nevill, 1998; Hopkins, 2000; Hopkins et al., 2009). For all the physiological measurements in RBR₁ and RBR₂, the normality of test-retest differences was tested using the Shapiro-Wilks statistic. Heteroscedasticity was present in some data (i.e. in the differences between RBR₁ and RBR₂). As non-normality of distribution was present, logarithmic transformation was performed. Differences in measured variables between consecutive trials were then examined using a paired Student’s t-test. Coefficients of variation (%), intra-class correlation coefficients (ICC), coefficients of reliability, and (F-type) 95% limits of agreement (LIMS) were calculated (Bland and Altman, 1986, 1999) from the log transformed variables where possible.

For the second (validation) part of the study, Pearson’s product moment correlation coefficient was used to identify relationships between the physiological variables that were assessed within RBR₁, and TT distances (i.e. B-TT, R-TT, and B-R TT distance (m)). Multiple linear regression was used to predict triathlon performance from TT, R-TT, and B-R TT distance (m)). Multiple linear regression was used to predict triathlon performance from TT, R-TT, and B-R TT distance (m)). Multiple linear regression was used to predict triathlon performance from TT, R-TT, and B-R TT distance (m)).

### Results

The subjects’ mean personal best OD times were 2:09:28 ± 0:04:51 hh:mm:ss (involving 40 km cycle times of 1:09:10 ± 0:04:13 hh:mm:ss and 10 km run times of 0:41:22 ± 0:02:53 hh:mm:ss). Their mean age, mass, and peak running speeds (Vmax) were 30.0 ± 2.0 years, 75.6 ± 1.6 kg, and 19.7 ± 0.3 km·h⁻¹. Their run ventilatory threshold (TRVT) of 3.5 ± 0.1 l·min⁻¹, occurred at 74.2 ± 3.4% VO2max. Details of their physiological responses to RBR₁, and RBR₂ are presented in Table 1. The athletes obtained significantly lower absolute cycle peak VO2 values than TRVO2max values (4.8 ± 0.2 vs. 4.2 ± 0.4 l·min⁻¹, p < 0.05).

No significant differences in any of the measured physiological variables were observed between RBR₁ and RBR₂. The 95% confidence limits for all such measures were similar across both trials. High levels of reliability (CV <10% and ICC <0.8) were also observed for most physiological variables, except [BLA] values (post R₁, Bsubmax and R₂; Table 2). The changes in absolute oxygen uptake, HR and [BLA] between R₁ and R₂, also displayed lower between-trial reliability than other measures (Table 2). Body mass (kg), before and immediately after the test - which lasted 00:50:00 ± 00:02:40 hh:mm:ss on average - was not significantly different.

The athletes’ mean power cycle outputs and run speeds during the cycle-run TT were 286.4 ± 43.3 W and 15.9 ± 1.1 km·h⁻¹, respectively. The equivalent cycle and run distances were 21.6 ± 1.8 km and 5.3 ± 0.4 km. Blood lactate concentration after the 21.6 ± 1.8 km cycle (B TT) was 9.5 ± 1.7 mM, as compared to 10.1 ± 3.0 mM after the 5.3 ± 0.4 km run (R TT). Multiple significant relationships were observed between the physiological measures

### Table 1. Selected responses of the age-group triathletes to RBR₁ and RBR₂ (mean ± s followed by the 95% confidence limits).

<table>
<thead>
<tr>
<th>Variable</th>
<th>RBR₁ (95% CI)</th>
<th>RBR₂ (95% CI)</th>
<th>Mean diff (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO₂ R₁ (l·min⁻¹)</td>
<td>3.67 ± 0.5 (3.25 - 4.09)</td>
<td>3.79 ± 0.34 (3.51 - 4.07)</td>
<td>0.12 ± 0.30 (0.36 - 0.25)</td>
</tr>
<tr>
<td>HR R₁ (beats·min⁻¹)</td>
<td>166 ± 10 (158 - 174)</td>
<td>164 ± 13 (153 - 175)</td>
<td>-1.63 ± 5.71 (-6.40 - 3.14)</td>
</tr>
<tr>
<td>[BLA] post R₁ (mM)</td>
<td>4.03 ± 1.81 (2.52 - 5.54)</td>
<td>3.89 ± 2.31 (1.96 - 5.82)</td>
<td>0.14 ± 1.47 (-1.32 to 1.61)</td>
</tr>
<tr>
<td>Bmax Abs VO₂post (l·min⁻¹)</td>
<td>4.19 ± 0.40 (3.86 - 4.52)</td>
<td>4.19 ± 0.49 (3.78 - 4.60)</td>
<td>0.01 ± 0.16 (-0.12 - 0.14)</td>
</tr>
<tr>
<td>Bmax Wpeak (W)</td>
<td>332.4 ± 33.6 (304.31 - 360.49)</td>
<td>332.9 ± 34.8 (303.81 - 361.99)</td>
<td>0.50 ± 11.25 (9.90 - 9.40)</td>
</tr>
<tr>
<td>Bmax HR peak (beats·min⁻¹)</td>
<td>182 ± 9 (174 - 189)</td>
<td>181 ± 9 (174 - 189)</td>
<td>-0.25 ± 2.49 (1.83 - 2.08)</td>
</tr>
<tr>
<td>[BLA] post Bmax (mM)</td>
<td>12.9 ± 3.1 (10.31 - 15.49)</td>
<td>12.9 ± 2.4 (10.89 - 14.91)</td>
<td>-0.02 ± 1.19 (0.98 - 1.00)</td>
</tr>
<tr>
<td>Bsubmax HR (beats·min⁻¹)</td>
<td>160 ± 12 (150 - 170)</td>
<td>160 ± 13 (149 - 171)</td>
<td>0.13 ± 3.76 (-3.01 - 3.33)</td>
</tr>
<tr>
<td>VO₂ Bsubmax (l·min⁻¹)</td>
<td>3.21 ± 0.30 (3.18 - 3.24)</td>
<td>3.21 ± 0.28 (3.19 - 3.23)</td>
<td>0.00 ± 0.13 (0.10 - 0.11)</td>
</tr>
<tr>
<td>[BLA] post Bsubmax (mM)</td>
<td>7.47 ± 3.86 (4.34 - 10.70)</td>
<td>7.16 ± 3.46 (4.27 - 10.05)</td>
<td>0.31 ± 2.81 (-2.50 to 3.12)</td>
</tr>
<tr>
<td>VO₂R₂ (l·min⁻¹)</td>
<td>3.68 ± 0.41 (3.34 - 4.02)</td>
<td>3.72 ± 0.38 (3.40 - 4.04)</td>
<td>0.04 ± 0.34 (0.21 - 3.77)</td>
</tr>
<tr>
<td>[BLA] post R₂</td>
<td>6.83 ± 3.39 (4.00 - 9.66)</td>
<td>6.76 ± 2.90 (4.34 - 9.18)</td>
<td>0.07 ± 5.63 (-5.56 to 5.70)</td>
</tr>
<tr>
<td>ΔHR R₁-R₂ (beats·min⁻¹)</td>
<td>8.6 ± 5.5 (4.0 - 13.2)</td>
<td>10.0 ± 6.7 (4.45 - 15.6)</td>
<td>1.4 ± 4.9 (-2.7 - 5.5)</td>
</tr>
<tr>
<td>Δ[BLA] R₁-R₂</td>
<td>2.80 ± 3.42 (-0.06 - 5.66)</td>
<td>2.86 ± 1.31 (1.76 - 3.96)</td>
<td>0.06 ± 2.69 (-2.19 - 2.31)</td>
</tr>
<tr>
<td>ΔVO₂ R₁-R₂ (l·min⁻¹)</td>
<td>0.0083 ± 0.19 (-0.15-0.17)</td>
<td>-0.07 ± 0.18 (-0.22 - 0.08)</td>
<td>-0.79 ± 0.16 (-0.22 - 0.06)</td>
</tr>
</tbody>
</table>

VO₂ oxygen output, R₁ first run section of RBR, HR heart rate, [BLA] blood lactate concentration, Bmax maximal incremental bicycle test section of RBR, Abs VO₂max absolute peak oxygen output (l·min⁻¹), Wpeak peak power output, Bsubmax submaximal cycle section of RBR, R₂ second run section of RBR, ΔHR R₁-R₂ change in heart rate between R₁ and R₂ of RBR, Δ[BLA] R₁-R₂ change in blood lactate concentration between R₁ and R₂ of RBR, ΔVO₂ R₁-R₂ change in VO₂ between R₁ and R₂ of RBR, No difference between matched variables (in the same row) was found between RBR₁ and RBR₂ at the 95% confidence level.
The selected reliability measures for RBR1 (as obtained from the log transformed variables, unless otherwise indicated).

<table>
<thead>
<tr>
<th>Variable</th>
<th>ICC</th>
<th>CV (%)</th>
<th>LIMa.e</th>
<th>CR</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO2R1 (l·min⁻¹)</td>
<td>0.68</td>
<td>5.87</td>
<td>-12.92</td>
<td>20.01</td>
</tr>
<tr>
<td>HR R1 (beats·min⁻¹)</td>
<td>0.92</td>
<td>2.6</td>
<td>-8.21</td>
<td>5.96</td>
</tr>
<tr>
<td>[BLA] post R1 (mM)</td>
<td>0.87</td>
<td>25.1</td>
<td>-72.82</td>
<td>49.68</td>
</tr>
<tr>
<td>Bmax Abs VO2peak</td>
<td>0.98</td>
<td>1.80</td>
<td>-8.21</td>
<td>5.96</td>
</tr>
<tr>
<td>Bmax Wpeak (W)</td>
<td>0.95</td>
<td>2.72</td>
<td>-6.08</td>
<td>7.06</td>
</tr>
<tr>
<td>Cycle HR peak (beats·min⁻¹)</td>
<td>0.98</td>
<td>0.96</td>
<td>-2.74</td>
<td>2.44</td>
</tr>
<tr>
<td>[BLA] post Bmax (mM)</td>
<td>0.99</td>
<td>3.00</td>
<td>-14.45</td>
<td>15.95</td>
</tr>
<tr>
<td>Bsubmax HR (beats·min⁻¹)</td>
<td>0.97</td>
<td>1.7</td>
<td>-4.53</td>
<td>4.57</td>
</tr>
<tr>
<td>VO2R2 (l·min⁻¹)</td>
<td>0.65</td>
<td>7.78</td>
<td>-18.21</td>
<td>20.46</td>
</tr>
<tr>
<td>[BLA] post R2</td>
<td>0.68</td>
<td>36.0</td>
<td>-86.63</td>
<td>83.90</td>
</tr>
</tbody>
</table>

ICC intra-class correlation coefficient, CV Typical error expressed as a coefficient of variation, LIMa.e limits of agreement (inferior-superior), CR coefficient of repeatability, VO2 oxygen output, R1 first run section of RBR, HR heart rate, [BLA] blood lactate concentration, Bmax maximal incremental bike test section of RBR, Abs VO2peak absolute peak oxygen output (l·min⁻¹), Wpeak peak power output, Bsubmax submaximal cycle section of RBR, R2 second run section of RBR, Δ [BLA]R1-R2 change in HR between R1 and R2 of RBR, ΔVO2 peak change in VO2 between R1 and R2 of RBR.

Table 3.  Selected Pearson’s product moment correlation coefficients (r) between physiological variables obtained in the TR VO2max and RBR1 tests, and the athletes’ laboratory time trial results.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Distance (km)</th>
<th>B TT</th>
<th>R TT</th>
<th>B-R TT</th>
</tr>
</thead>
<tbody>
<tr>
<td>TR VO2max (l·min⁻¹)</td>
<td>.868 *</td>
<td>.557</td>
<td>.868</td>
<td>*</td>
</tr>
<tr>
<td>TR VO2max (ml·kg⁻¹·min⁻¹)</td>
<td>.402</td>
<td>.003</td>
<td>.402</td>
<td></td>
</tr>
<tr>
<td>TR Vmax</td>
<td>-.082</td>
<td>.640</td>
<td>-.104</td>
<td></td>
</tr>
<tr>
<td>% of TRVO2max at 15 km·h⁻¹</td>
<td>-.171</td>
<td>-.832</td>
<td>*</td>
<td>.143</td>
</tr>
<tr>
<td>VO2 R1 (l·min⁻¹)</td>
<td>-.110</td>
<td>-.830</td>
<td>*</td>
<td>.39</td>
</tr>
<tr>
<td>[BLA] post R1 of RBR</td>
<td>-.043</td>
<td>-.762</td>
<td></td>
<td>.474</td>
</tr>
<tr>
<td>[BLA] post Bmax (mM)</td>
<td>.213</td>
<td>-.921</td>
<td>*</td>
<td>-.016</td>
</tr>
<tr>
<td>Bmax Wpeak (W)</td>
<td>.942 **</td>
<td>-.377</td>
<td>.885</td>
<td>*</td>
</tr>
<tr>
<td>Bmax VO2peak (W·kg⁻¹)</td>
<td>.694</td>
<td>.055</td>
<td>.736</td>
<td></td>
</tr>
<tr>
<td>Bmax submax (l·min⁻¹)</td>
<td>.885 **</td>
<td>-.032</td>
<td>.866</td>
<td>*</td>
</tr>
<tr>
<td>[BLA] post Bmax (mM)</td>
<td>.484</td>
<td>.392</td>
<td>.551</td>
<td></td>
</tr>
<tr>
<td>% of VO2peak at 3W·kg⁻¹</td>
<td>-.770 *</td>
<td>-.740</td>
<td>.550</td>
<td></td>
</tr>
<tr>
<td>Bsubmax B EC</td>
<td>-.272</td>
<td>-.376</td>
<td>-.503</td>
<td></td>
</tr>
<tr>
<td>[BLA] post Bsubmax (mM)</td>
<td>-.380</td>
<td>-.120</td>
<td>-.140</td>
<td></td>
</tr>
<tr>
<td>VO2 R2 (l·min⁻¹)</td>
<td>.110</td>
<td>-.830</td>
<td>*</td>
<td>.390</td>
</tr>
<tr>
<td>ECRun R2</td>
<td>-.325</td>
<td>-.590</td>
<td>.015</td>
<td></td>
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<tr>
<td>ΔHRR1-R2 (beats·min⁻¹)</td>
<td>-.330</td>
<td>.860</td>
<td>.060</td>
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<tr>
<td>Δ [BLA]R1-R2</td>
<td>-.580</td>
<td>.200</td>
<td>-.880</td>
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<tr>
<td>ΔVO2R1-R2</td>
<td>-.170</td>
<td>.340</td>
<td>.120</td>
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<tr>
<td>ΔECR1-R2</td>
<td>.508</td>
<td>-.358</td>
<td>.589</td>
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</table>

TT cycle section of the time-trial (TT), R TT run section of TT, B-R TT cycle-run TT, TR treadmill, VO2 max maximal oxygen uptake, Vmax peak TR running speed during TRVO2max test, VO2 R1 oxygen uptake, R1 first submaximal run of RBR, ECrun running economy, [BLA] blood lactate concentration, Bmax maximal incremental section of RBR1, Wmax peak power output, VO2peak peak oxygen uptake, B-EC cycle economy, Bsubmax submaximal cycle section of RBR, R2 second run of RBR, Δ [BLA]R1-R2 change in HR between R1 and R2 of RBR, ΔVO2 R1-R2 change in VO2 between R1 and R2 of RBR, ΔECR1-R2 change in economy between R1 and R2 of RBR, * significant at the p < 0.05 level, ** significant at the p < 0.02 level.
Discussion

Both the subject characteristics and their physiological responses (Tables 1 and 2), confirmed them as well-trained age-group but not elite triathletes. In common with the athletes of Millet et al. (2003), Millet and Bentley (2004), and Schabort et al. (2000), the subjects displayed significantly greater VO2max values for running than for cycling (p < 0.05). As the VO2 values of the athletes were reproducible this is unlikely to have been due to fatigue from R1 in Bmax. However, the athletes in this study were older and possessed lower TR VO2max, B VO2peak, and Wpeak (W), than the Senior male Elites of previous work (Millet et al., 2003; Millet and Bentley, 2004; Schabort et al., 2000). The mean Wpeak attained by the triathletes during Bmax was 332 ± 9 W, as compared to 385 ± 50 W in Millet et al. (2003) and to 385 ± 14 W in Schabort et al. (2000), respectively.

The triathletes exercised during R1 and R2 of RBR1 at 77.7 ± 10.4% and 78.1 ± 10.9% of TR VO2max respectively (i.e. at an almost identical intensity to that observed by Schabort et al. (2000) for elite triathletes performing an isolated run at the same speed). [BLA] was higher, however, post R1 than was observed by Schabort et al. (2000) for an isolated run (4.03 ± 1.81 and 3.89 ± 2.31 mM for RBR1 and RBR2, respectively, vs. 1.72 ± 0.3 mM) (Table 2). Mean cycle intensity during Bsubmax was 66.8 ± 5.1% of Wpeak, as compared to 80% during the Bsubmax section of the original RBR test (Millet et al., 2003; Millet and Bentley, 2004).

Importantly, as the measured physiological variables did not differ significantly between RBR1 and RBR2, they appear to exhibit good levels of test-retest error. Moreover, the RBR test appears to be valid relative to the distances covered within the cycle-run TT.

Almost all of the physiological measures in RBR displayed CV’s of less than 10% and ICC’s greater than 0.8 (Table 3). The error values that were obtained within RBR1 and RBR2 for absolute Wpeak (W) and BVO2peak, specifically, were also similar to those of “effective practical use” (Balmer et al., 2000; Kuipers et al., 1985), and are therefore reliable (Atkinson and Nevill, 1998). The poorest inter-trial reliability was displayed by [BLA] post R1 (mM) (ICC 0.87, CV 25.1%), [BLA] post Bsubmax (mM) (ICC 0.87, CV 25.1%), [BLA] post R1 (CV 22.95%). That is, the CV of all the [BLA] measures, apart from that taken immediately post Bsubmax was above the recommended standard for reliability of 15% (Gore, 2000). Our values for the change in HR and [BLA] between the two consecutive runs of the RBR (i.e. ∆HRR1-R2 and ∆[BLA]R1-R2) in that order, also appeared to be less reliable.

It was not possible to obtain meaningful ICC, CV, or LIMREC for the logged values of ∆[BLA]R1-R2, owing to a lack of consistency in the direction of any such changes, but the mean differences and 95% confidence limits for ∆HRR1-R2 and ∆[BLA]R1-R2 Variables were 0.79 ± 0.16 (-0.22-0.06), and 0.06 ± 2.70 (-2.20-2.32) respectively. A potential five beat per minute difference in HR and a 2 mM difference in [BLA] from “reality” might cause concern to the coach who is using the RBR results to assess changes in cycle-run transition ability over time. We suggest, therefore, that any such judgement be based on the combination of both these values and the respiratory data, rather than on either HR or [BLA] (and especially not [BLA]) (Sirotic and Coutts, 2008) in isolation.

Laursen et al. (2007) have suggested that a reliable test may also be defined as one in which “the described measurement error is judged to be acceptable on the basis of its sensitivity for detecting real change” (or difference). Conducting a comparative assessment of the physiological responses to the RBR test of athlete groups such as OD vs. long distance specialists, who, because of differences in their training (Vleck et al., 2010), would be expected to differ in their ability to adapt to a cycle-run transition may therefore provide further insight into the test’s appropriateness to a specific athlete population.

To the coach, “real change” normally means competitively significant change. A longitudinal prospective survey of the extent to which athletes’ responses to the test can change over the course of the competitive season, analysed in conjunction with their race results, may yield further information regarding the usefulness of our protocol.

Although we did not use competition data to validate our test we obtained similar results regarding which physiological variables could be important, to those that have (Schabort et al., 2000; Millet et al., 2003; Millet and Bentley, 2004) (Table 2). For example, we observed a significant relationship between RBR1 absolute BVO2peak values and total TT distance. This is similar to the r value (of -0.82, p < 0.05) that was observed by Schabort et al. (2000) for the relationship between absolute BVO2peak (from an isolated cycle test) and total triathlon time. The correlation coefficient that we obtained between Wpeak in RBR1 and total TT distance (r = 0.87, p < 0.05) approximated that obtained between Wpeak and total OD time by Schabort et al. (2000) (r = -0.86, p < 0.05) and was better than that obtained between Wpeak for OD time within Millet’s RBR test (r = -0.71, p < 0.001) (Millet et al., 2003). As subject ability level and the method that was used to validate the test differed between these two RBR studies, it is impossible to speculate to what extent the strength of r may be influenced by protocol differences within their maximal incremental cycle section, and thus, which test may be better on which occasion.

We additionally observed a similar r value (r = -0.83, p < 0.05) for the relationship between % of VO2max at 15 km·h-1 (in R1) and run TT distance, as was observed between the same variable and both 10-km running time (also r = -0.83, p < 0.01) and total triathlon time (r = -0.81, p < 0.05) by Schabort et al. (2000). Laurenson et al. (1993) had previously seen similarly high correlations, in female triathletes, between this same measure of efficiency and triathlon time. We however, found no such relationship between running economy (Miura et al., 1997) and performance, agreeing with Schabort et al.
(2000) but not with Millet et al. (2003). Again it is not clear to what extent the difference between this and the original RBR protocol in what was related to performance is due to protocol differences between the two tests. In the original test, athletes were asked to perform R1 and R2 at a speed corresponding to their current personal best OD triathlon run time.

Both [BLA] post R1 (r=-0.92, p<0.02) and [BLA] post B_{\text{abs max}} (r=-0.87, p<0.05) were also highly correlated with R-TT distance (r=-0.88, p<0.05). Moreover, the Δ[BLA]_{R1-R2} was strongly related to total TT distance (r=-0.88, p<0.05), as ΔHR_{R1-R2} was to total R-TT distance (r=0.86, p<0.05). We consider this significant relationship between both Δ[BLA]_{R1-R2} and ΔHR_{R1-R2} and performance to be an important justification for using combined (as opposed to isolated) cycle and run testing in triathletes. We cannot report whether a similar relationship exists when these variables are measured within the Millet test (Millet et al., 2003), as [BLA] values have not been reported for it. However, as discussed above, care should be taken in the use of [BLA] and HR related values to assess the degree of training adaptation that may have taken place between successive tests (Morton et al., 2012).

As regards the appropriateness of our choice of the 30-minute cycle - 20-minute run TT to validate the physiological measures obtained within RBR, we note that Hue (2003) found end-cycle [BLA] and total running distance (Table 2) to be significantly correlated (r = 0.83, p < 0.05 and -0.92, p < 0.01, respectively) with total drafted OD time. Our athletes started the TT from a 15 km·h⁻¹ rolling start, rather than at a “speed close to their performance level in a classic triathlon” (Hue, 2003), but otherwise the two TT protocols were identical. We doubt that this change would have affected the TT post-cycle [BLA] and run distance values. Although it would have been better if we had also validated our test results against competition data, and a prediction equation obtained within the Millet test (Millet et al., 2003), as [BLA] values have not been reported for it. Moreover, as discussed above, care should be taken in the use of [BLA] and HR related values to assess the degree of training adaptation that may have taken place between successive tests (Morton et al., 2012).

In conclusion, our new RBR test allows reproducible measurement of B_{\text{max}}, W_{\text{peak}} (W) and B_{\text{abs max}} Abs VO₂_{\text{peak}}, all of which have been consistently related to triathlon performance. The test appears to be reliable, and valid relative to laboratory time-trial performance, in male OD age-groupers. However, further investigation into the sensitivity of the variables that are assessed when the modified RBR is used to test an age-group population, relative to training modification and actual race performance, is warranted.

References


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**Key points**

- It is extremely important to ensure that the measurements made as part of research or athlete support work are adequately reliable and valid.
- The modified Millet triathlete “Run-Bike-Run” (RBR) test allows both for important physiological variables that are normally obtained from isolated tests (such as cycle VO2peak and peak power output) to be determined, and for measurement of the extent to which an athlete adapts to a cycle-run transition (T2).
- The data reported in this paper regarding the test-retest reliability of the modified RBR, and its validity relative to cycle-run time-trial performance in male age-group triathletes, may help coaches determine the extent to which changes on test measures are likely due to training adaptation rather than to measurement error.

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