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Research article

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 $\dot{V}O_{2max}$ 63.8 ± 1.9 ml·kg^{-1}·min^{-1}, cycle $\dot{V}O_{2peak}$ 56.7 ± 5.1 ml·kg^{-1}·min^{-1}) performed four trials over 10 days. Trial 1 (TR$\dot{V}O_{2max}$) was an incremental treadmill running test. Trials 2 and 3 (RBR_1 and RBR_2) 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 ($\dot{V}O_2$), heart rate (HR), or blood lactate concentration ([BLA]) were evidenced between RBR_1 and RBR_2. 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. ICC <0.8, CV<10%) were observed for most (logged) measurements. However [BLA] post R_1 (ICC 0.87, CV 25.1%), [BLA] post B_{submax} (ICC 0.99, CV 16.31) and [BLA] post R_2 (ICC 0.51, 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 $\dot{V}O_{2peak}$, cycle peak power output, and the change between R_1 and R_2 (deltaR_1R_2) in [BLA] were most highly related to overall TT distance ($r = 0.89$, $p < 0.01$; $r = 0.94$, $p < 0.02$; $r = 0.86$, $p < 0.05$, respectively). The percentage of TR $\dot{V}O_{2max}$ at 15 km·h^{-1}, and deltaR_1R_2 HR, were also related to run TT distance ($r = -0.83$ and 0.86, 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 ($\dot{V}O_{2peak}$); 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 $\dot{V}O_{2peak}$ 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 (R1) of the test acts as a control to which physiological data from the second, post-

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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 $\dot{V}O_{2max}$ ($r = -0.80$, $p < 0.001$) and cycle peak power output (W_{peak}) ($r = -0.85$, $p < 0.001$), 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 $\dot{V}O_{2max}$ and W_{peak} 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 W_{peak} 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% W_{peak} 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 sequential "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 $km \cdot h^{-1}$ - 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 W_{peak} 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 $W \cdot kg^{-1}$ rather than the 4 $W \cdot kg^{-1}$ the [BLA] after which was demonstrated to be related to OD performance (Schabort et al., 2000) because 4 $W \cdot kg^{-1}$ 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 ($TR\dot{V}O_{2max}$); (2) and (3) the "Run-Bike-Run" trial (termed RBR_1 on its first occasion and, when repeated, RBR_2); and 4) a laboratory based 30-minute cycle–20-min run distance trial (TT). $TR\dot{V}O_{2max}$ was completed first and the remaining tests were performed in randomised counter-balanced 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 $h \cdot wk^{-1}$), 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 ($TR\dot{V}O_{2max}$)

The $TR\dot{V}O_{2max}$ was conducted on a Powerjog treadmill (Powerjog, UK) and was preceded by a 5-minute warm up at 8 $km \cdot h^{-1}$ and stretching. The test commenced at 8 $km \cdot h^{-1}$ and 1% gradient (Jones and Doust, 1996), and involved increments of 1 $km \cdot h^{-1}$ 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 ($K4B^2$, 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 (TRV_{max}) was recorded as the highest speed completed over 60 s. Treadmill (TR) HR_{max} ($b \cdot min^{-1}$) was defined as the highest consecutive 5 s mean during the test. Maximum run oxygen uptake ($TR\dot{V}O_{2max}$) 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-$\dot{V}O_2$ relationship), 85% of age-related HR_{max}, 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 $\dot{V}E$, $\dot{V}E/\dot{V}CO_2$ and $\dot{V}E/\dot{V}O_2$ 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%.

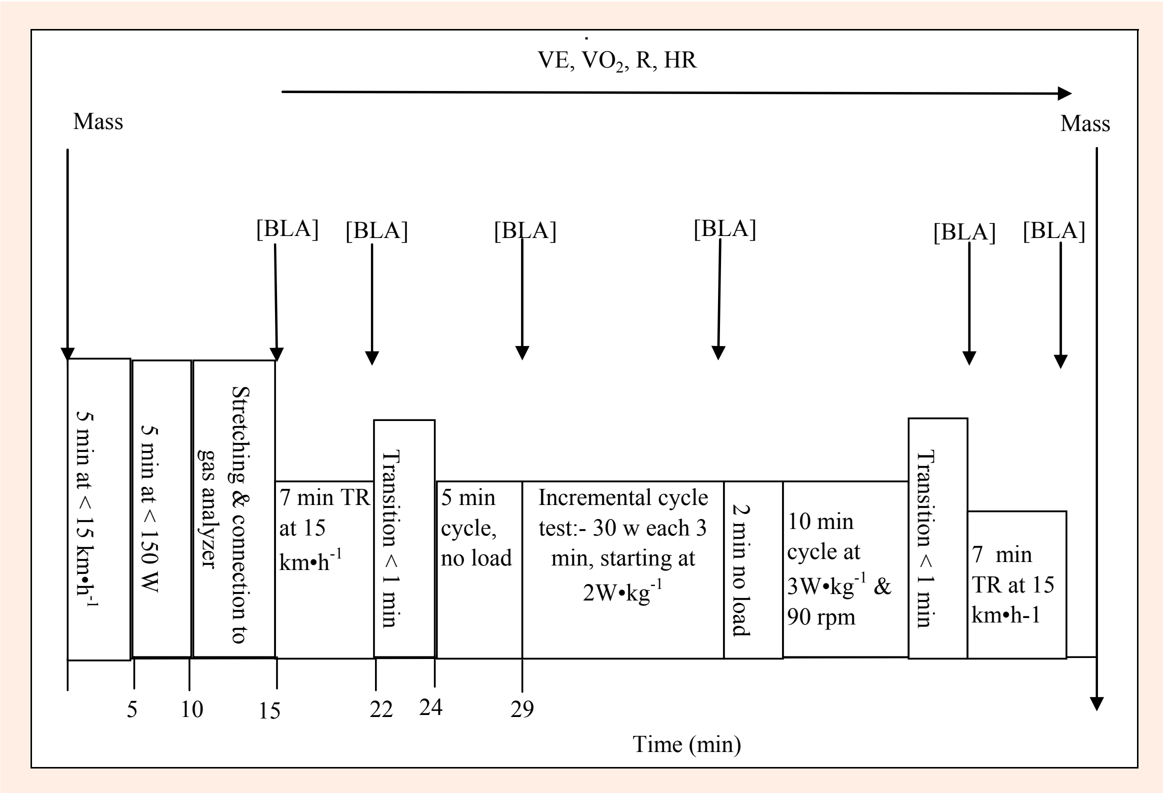

Figure 1. Protocol diagram of the study

Run-bike-run (RBR) trials

On two other occasions (RBR_1 and RBR_2) each subject performed a sequential run-bike-run trial (Figure 1) that comprised: 1) submaximal running (R_1): 2) a maximal incremental cycle test (B $\dot{V}O_{2peak}$); 3) submaximal (B_{sub}) cycling; and 4) an additional submaximal run (R_2). 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.

R_1 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. $B_{max}\dot{V}O_{2peak}$). $B_{max}\dot{V}O_{2peak}$ 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 ~90 rev·min^{-1} (Lucia et al., 2001). The subject then performed 2 minutes of unloaded cycling before part 3 of the test (B_{submax}). B_{submax} involved 10 minutes of cycling at 90 rev·min^{-1} and 3 W·kg^{-1}. Within 60 s of completion of $B_{submax,}$ 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 (R_2) 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. R_1, $B\dot{V}O_{2peak}$, B_{submax} and R_2, 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 $B\dot{V}O_{2peak}$, $\dot{V}O_{2peak}$, HR_{max} (b·min^{-1}) and the VT were calculated as previously described (see *Incremental running test*). Peak power output (W_{peak}) (W) for $B\dot{V}O_2$ was calculated using the equation of Hawley and Noakes (1992):

$$W_{peak} = W_f + (t/180 \text{ s x } 30 \text{ W})$$

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

During B_{submax}, cycle economy (B_EC) was measured as the ratio of the power output (W) to VO_2 (l·min^{-1}) consumed (Millet et al., 2004). In the last 60 s of R_1 and R_2, $\dot{V}O_2$ (ml·kg^{-1}·min^{-1}) was averaged and economy (EC_{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 minute 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 RBR_1 and RBR_2 the normality of test-retest differences was tested using the Shapiro-Wilks statistic. Heteroscedasticity was examined by scatterplots of, and by calculating the Pearson's product moment correlation coefficient between, absolute differences and individual athlete means for RBR_1 and RBR_2. As non-normality of distribution was present in some data (i.e. in the differences between RBR_1 and RBR_2 for [BLA] post B_{max}, in [BLA] post B_{submax}, and in absolute R_2 $\dot{V}O_2$), as was heteroscedasticity (e.g. in the case of the change in [BLA] between R_1 and R_2 ($\Delta[BLA]_{R1-R2}$)) 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 (LIM_{AG}) 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 RBR_1, 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 the best physiological correlates/variables obtained in RBR_1, so as to assess which of these might have most influence on said performance.

The "Statistical Package for the Social Sciences" (SPSS, version 17.0, High Wycombe, UK) and an Excel spread sheet (Hopkins, 2009) were used. Statistical significance was set at $p < 0.05$.

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 (V_{max}) 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% TR$\dot{V}O_{2max}$. Details of their physiological responses to RBR_1 and RBR_2 are presented in Table 1. The athletes obtained significantly lower absolute cycle peak $\dot{V}O_2$ values than TR$\dot{V}O_{2max}$ 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 RBR_1 and RBR_2. 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 R_1, B_{submax} and R_2; Table 2). The changes in absolute oxygen uptake, HR and [BLA] between R_1 and R_2, 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 RBR_1 and RBR_2 (mean ± *s* followed by the 95% confidence limits).

Variable	RBR_1 (95% CI)	RBR_2 (95% CI)	Mean diff (95% CI)
$\dot{V}O_2$ R_1 (l·min^{-1})	3.67 ± 0.5 (3.25 - 4.09)	3.79 ± 0.34 (3.51 - 4.07)	0.12 ± 0.30 (0.36 - 0.25)
HR R_1 (beats·min^{-1})	166 ± 10 (158 - 174)	164 ± 13 (153 - 175)	-1.63 ± 5.71 (-6.40 - 3.14)
[BLA] post R_1 (mM)	4.03 ± 1.81[a] (2.52 - 5.54)	3.89 ± 2.31 (1.96 - 5.82)	0.14 ± 1.47 (-1.32 to 1.61)
B_{max} Abs $\dot{V}O_{2peak}$ (l·min^{-1})	4.19 ± 0.40 (3.86 - 4.52)	4.19 ± 0.49 (3.78 - 4.60)	0.01 ± 0.16 (-0.12 - 0.14)
B_{max} W_{peak} (W)	332.4 ± 33.6 (304.31 - 360.49)	332.9 ± 34.8 (303.81 - 361.99)	0.50 ± 11.25 (9.90 - 9.40)
B_{max} HR_{peak} (beats·min^{-1})	182 ± 9 (174 - 189)	181 ± 9 (174 - 189)	-0.25 ± 2.49 (1.83 - 2.08)
[BLA] post B_{max} (mM)	12.9 ± 3.1 (10.31 - 15.49)	12.9 ± 2.4 (10.89 - 14.91)	-0.02 ± 1.19 (0.98 - 1.00)
B_{submax} HR (beats·min^{-1})	160 ± 12 (150 - 170)	160 ± 13 (149 - 171)	0.13 ± 3.76 (-3.01 - 3.3)
$\dot{V}O_2$ B_{submax} (l·min^{-1})	3.21 ± 0.030 (3.18 - 3.24)	3.21 ± 0.028 (3.19 - 3.23)	0.00 ± 0.13 (0.10 - 0.11)
[BLA] post B_{submax} (mM)	7.47 ± 3.86 (4.24 - 10.70)	7.16 ± 3.46 (4.27 - 10.05)	0.31 ± 2.81 (-2.50 to 3.12)
$\dot{V}O_2R_2$ (l·min^{-1})	3.68 ± 0.41 (3.34 - 4.02)	3.72 ± 0.38 (3.40 - 4.04)	0.04 ± 0.34 (4.21 - 3.77)
[BLA] post R_2	6.83 ± 3.39[a] (4.00 - 9.66)	6.76 ± 2.90 (4.34 - 9.18)	0.07 ± 5.63 (-5.56 to 5.70)
ΔHR_{R1-R2} (beats·min^{-1})	8.6 ± 5.5 (4.0 – 13.2)	10.0 ± 6.7 (4.4 – 15.6)	1.4 ± 4.9 (-2.7 – 5.5)
$\Delta[BLA]_{R1-R2}$	2.80 ± 3.42 (-0.06 - 5.66)	2.86 ± 1.31 (1.76 - 3.96)	0.06 ± 2.69 (-2.19 - 2.31)
$\Delta\dot{V}O_{2R1-R2}$ (l·min^{-1})	0.0083 ± 0.19 (-0.15-0.17)	-0.07 ± 0.18 (-0.22 – 0.08)	-0.79 ± 0.16 (-0.22 – 0.06)

$\dot{V}O_2$ oxygen output, R_1 first run section of RBR, HR heart rate, [BLA] blood lactate concentration, B_{max} maximal incremental bike test section of RBR, Abs $\dot{V}O_{2peak}$ absolute peak oxygen output (l·min^{-1}), W_{peak} peak power output, B_{submax} submaximal cycle section of RBR, R_2 second run section of RBR, ΔHR_{R1-R2} change in HR between R_1 and R_2 of RBR_1 $\Delta[BLA]_{R1-R2}$ change in blood lactate concentration between R_1 and R_2 of RBR_1, $\Delta\dot{V}O_{2\,R1-R2}$ change in $\dot{V}O_2$ between R_1 and R_2 of RBR_1. No difference between matched variables (in the same row) was found between RBR_1 and RBR_2 at the 95% confidence level.

Table 2. Selected reliability measures for RBR_1 *vs.* RBR_2 (as obtained from the log transformed variables, unless otherwise indicated).

Variable	ICC	CV (%)	LIM_{AG}	CR
VO_2 R_1 ($l \cdot min^{-1}$)	.68	5.87	-12.92-20.01	16.46
HR R_1 ($beats \cdot min^{-1}$)	.92	2.6	-8.21-5.96	7.08
[BLA] post R_1 (mM)	.87	25.1	-72.82-49.68	61.25
B_{max} Abs VO_{2peak}	.98	1.80	-8.21-5.96	7.08
B_{max} W_{peak} (W)	.95	2.72	-6.08-7.06	6.93
Cycle HR_{peak} ($beats \cdot min^{-1}$)	.98	0.96	-2.74-2.44	2.59
[BLA] post B_{max} (mM)	.99	3.00	-14.45-15.95	15.20
B_{submax} HR ($beats \cdot min^{-1}$)	.97	1.7	-4.53-4.57	4.55
VO_2 B_{submax} ($l \cdot min^{-1}$)	.95	2.37	-7.70-7.65	7.68
[BLA] post B_{submax} (mM)	.99	16.31	-45.36-36.27	40.82
VO_2R_2 ($l \cdot min^{-1}$)	.65	7.78	-18.21-20.46	19.34
[BLA] post R_2	.68	36.0	-86.63-83.90	85.26

ICC intra-class correlation coefficient, CV Typical error expressed as a coefficient of variation, LIM_{AG} limits of agreement (inferior-superior), CR coefficient of repeatability, VO_2 oxygen output, R_1 first run section of RBR, HR heart rate, [BLA] blood lactate concentration, B_{max} maximal incremental bike test section of RBR, Abs VO_{2peak} absolute peak oxygen output ($l \cdot min^{-1}$), W_{peak} peak power output, B_{submax} submaximal cycle section of RBR, R_2 second run section of RBR, ΔHR_{R1-R2} change in HR between R_1 and R_2 of RBR_1 Δ $[BLA]_{R1-R2}$ change in blood lactate concentration between R_1 and R_2 of RBR_1, $\Delta VO_{2\ R1-R2}$ change in VO_2 between R_1 and R_2 of RBR_1.

that were assessed within RBR_1 and B-TT and R-TT distances (for which the athletes exercised at 86.2 ± 6.6% cycle W_{peak} and 81.0 ± 4.5% TR V_{max}, respectively) (Table 3).

Both RBR_1 absolute cycle W_{peak} and absolute cycle VO_{2peak} were significantly correlated with B-TT distance ($r = 0.94$, $p < 0.001$ and 0.89, $p < 0.02$, respectively), as was the [BLA] immediately post B_{max} ($r = 0.77$, $p < 0.05$). R-TT distance was related to the % of TR VO_{2max} that was elicited at 15 $km \cdot h^{-1}$ in R_1 ($r = -0.83$, $p < 0.05$), to [BLA] post R_1 ($r = -0.92$, $p < 0.05$), to [BLA] at the end of B_{submax} ($r = -0.87$, $p < 0.05$), and to the change in HR between consecutive runs of RBR_1 (ΔHR_{R1-R2}) ($r = 0.86$, $p < 0.05$). Total TT distance was additionally related to absolute BVO_{2peak} ($r = 0.89$, $p < 0.02$) and to the difference in blood lactate concentration between R_1 and R_2 of RBR_1 ($\Delta[BLA]_{R1-R2}$) ($r = -0.88$, $p < 0.05$). The best correlates of TT performance in RBR_1 generated the following prediction equation: y = 18.26173+1.528404X1+0.007845X2-0.16085X3 where X1 = absolute B VO_{2peak} ($l \cdot min^{-1}$);

Table 3. Selected Pearson's product moment correlation coefficients (r) between physiological variables obtained in the TR VO_{2max} and RBR_1 tests, and the athletes' laboratory time trial results.

	Distance (km)		
Variable	B TT	R TT	B-R TT
TR VO_{2max} ($l \cdot min^{-1}$)	.868 *	.557	.868 *
TR VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	.402	.003	.402
TR V_{max}	-.082	.640	-.104
% of $TRVO_{2max}$ at 15 $km \cdot h^{-1}$	-.171	-.832 *	.143
VO_2 R_1 ($l \cdot min^{-1}$)	-.110	-.830 *	.39
EC_{Run} R_1 of RBR_1	-.043	-.762	.474
[BLA] post R_1	.213	-.921 **	-.016
B_{max} W_{peak} (W)	.942 **	-.377	.885 *
$B_{max} W_{peak}$ ($W \cdot kg^{-1}$)	.694	.055	.736
B_{max} VO_{2peak} ($l \cdot min^{-1}$)	.885 **	-.032	.886 *
B_{max} VO_{2peak} ($ml \cdot kg^{-1} \cdot min^{-1}$)	.484	.392	.551
[BLA] post B_{max} (mM)	.770 *	-.740	.550
% of BVO_{2peak} at $3W \cdot kg^{-1}$	-.272	-.376	-.503
B_{submax} B EC	-.380	-.120	-.140
[BLA] post B_{submax} (mM)	.910	-.870 *	-.210
VO_2 R_2 ($l \cdot min^{-1}$)	.110	-.830 *	.390
EC_{Run} R_2	-.325	-.590	.015
ΔHR_{R1-R2} ($beats \cdot min^{-1}$)	-.330	.860 *	.060
$\Delta[BLA]_{R1-R2}$	-.580	.200	-.880 *
ΔVO_{2R1-R2}	.170	-.340	.120
ΔEC_{R1-R2}	.508	-.358	.589

B TT cycle section of the time-trial (TT), R TT run section of TT, B-R TT cycle-run TT, TR treadmill, VO_2 max maximal oxygen uptake, V_{max} peak TR running speed during $TRVO_{2max}$ test, VO_2 R_1 oxygen uptake, R_1 first submaximal run of RBR_1, EC_{Run} running economy, [BLA] blood lactate concentration, B_{max} maximal incremental section of RBR_1, W_{peak} peak power output, VO_{2peak} peak oxygen uptake, B-EC cycle economy, B_{submax} submaximal cycle section of RBR_1, R_2 second run of RBR_2, ΔHR_{R1-R2} change in HR between R_1 and R_2 of RBR_1 Δ $[BLA]_{R1-R2}$ change in blood lactate concentration between R_1 and R_2 of RBR_1, $\Delta VO_{2\ R1-R2}$ change in VO_2 between R_1 and R_2 of RBR_1, ΔEC_{R1-R2} change in economy between R_1 and R_2 of RBR_1, * significant at the $p < 0.05$ level, ** significant at the $p < 0.02$ level

X2 = W_{peak} (w) and X3 = $\Delta[BLA]_{R1-R2}$), with an r^2 value of 0.98. No significant relationships between EC_{Run} in R_1 or R_2, or ΔEC_{R1-R2}, and B-TT, R-TT or C-R TT distance were observed.

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 VO_{2max} values for running than for cycling ($p < 0.05$). As the VO_2 values of the athletes were reproducible this is unlikely to have been due to fatigue from R1 in B_{max}. However, the athletes in this study were older and possessed lower TR VO_{2max}, B VO_{2peak}, and W_{peak} (W), than the Senior male Elites of previous work (Millet et al., 2003; Millet and Bentley, 2004; Schabort et al., 2000). The mean W_{peak} attained by the triathletes during B_{max} 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 R_1 and R_2 of RBR_1 at 77.7 ± 10.4% and 78.1 ± 10.9% of TR VO_{2max} 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 R_1 than was observed by Schabort et al. (2000) for an isolated run (4.03 ± 1.81 and 3.89 ± 2.31 mM for RBR_1 and RBR_2, respectively, *vs*. 1.72 ± 0.3 mM) (Table 2). Mean cycle intensity during B_{submax} was 66.8 ± 5.1% of W_{peak}, as compared to 80% during the B_{submax} 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 RBR_1 and RBR_2 for absolute W_{peak} (W) and BVO_{2peak}, 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 R_1 (mM) (ICC 0.87, CV 25.1%), [BLA] post B_{submax} (mM) (ICC 0.99, CV 16.31%, and [BLA] post R_2 (ICC 0.51, CV 22.95%). That is, the CV of all the [BLA] measures, apart from that taken immediately post B_{submax}, 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.* ΔHR_{R1-R2} and $\Delta[BLA]_{R1-R2}$) in that order, also appeared to be less reliable.

It was not possible to obtain meaningful ICC, CV, or LIM_{AG} for the logged values of $\Delta[BLA]_{R1-R2}$, owing to a lack of consistency in the direction of any such changes, but the mean differences and 95% confidence limits for ΔHR_{R1-R2} and Δ $[BLA]_{R1-R2}$ 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 RBR_1 absolute BVO_{2peak} 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 BVO_{2peak} (from an isolated cycle test) and total triathlon time. The correlation coefficient that we obtained between W_{peak} in RBR_1 and total TT distance ($r = 0.87$, $p < 0.05$) approximated that obtained between W_{peak} and total OD time by Schabort et al. (2000) ($r = -0.86$, $p < 0.05$) and was better than that obtained between W_{peak} 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 VO_{2max} at 15 $km \cdot h^{-1}$ (in R_1) 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 R_1 and R_2 at a speed corresponding to their current personal best OD triathlon run time.

Both [BLA] post R_1 (r=-0.92, p<0.02) and [BLA] post B_{submax} (r=-0.87, p<0.05) were also highly correlated with R-TT distance (r=-0.88, p<0.05). Moreover, the $\Delta[BLA]_{R1-R2}$ 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 $\Delta[BLA]_{R1-R2}$ 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 $km \cdot h^{-1}$ 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 from 8 subjects lacks adequate statistical power, our results agree with the literature (Millet et al., 2003, Millet and Bentley, 2004; Schabort et al., 2000) as regards which physiological variables (e.g. BVO_{2peak} and B W_{peak}, post-cycle [BLA], and $\Delta[BLA]_{R1-R2}$) are related to TT or race performance.

Conclusion

Our new RBR test allows reproducible measurement of B_{max} W_{peak} (W) and B_{max} Abs $\dot{V}O_{2peak}$, 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.

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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 VO_{2peak} 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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