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Reliability of performance and associated physiological responses during simulated sprint-distance triathlon

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Abstract

Many different methods of simulating triathlon performance in controlled conditions have been developed without establishing the reliability of these assessments. The aim of this study was to determine the reliability of performance and physiological measures during simulated triathlon. Seven trained male triathletes completed initial familiarization, followed by three separate simulated sprint-distance triathlon trials (750 m swim, 500 kJ bike, 5 km run), using a 25 m pool, an electromagnetically braked cycle ergometer and motorized treadmill. Performance (time and mean cycling power) and physiological variables (oxygen uptake, ventilation, heart rate and blood lactate concentration) were measured throughout. Reliability between trials was assessed using one-way analysis of variance (ANOVA), coefficient of variation (CV), intraclass correlation coefficient (ICC) and ratio limits of agreement (LoA). No significant differences were found in performance or physiological variables measured across simulated triathlon trials. High levels of reliability (CV <10% and ICC >0.8) were observed for all performance measures (except transitions) and a majority of physiological variables. Measurement of blood lactate concentration displayed the poorest reliability throughout, with CV's up to 17.3% and ICC's as low as 0.4. Ratio LoA for total performance time were similar between trials 1-2 (1.008 */÷ 1.077) and trials 2-3 (1.004 */÷ 1.064). Based on these results simulated sprint-distance triathlon allows for reliable measurement of performance parameters and associated physiological responses in a controlled environment. This reliability data should be considered by simulated triathlon studies when determining statistical power and sample sizes, to allow for more rigorous detection of genuine changes between trials.

Keywords: reproducibility, swimming, bicycling, running, multisport, triathlete

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Introduction

In triathlon, overall performance time is dependant on the sequential completion of swimming, cycling and running phases, which are linked by brief 'transition' periods. The distance covered during each phase is dependant on the category of competition, ranging from the shortest 'Sprint' distance events (750 m swim, 20 km bike, 5 km run) to the 'Ironman' format (3.8 km swim, 180 km bike, 42.2 km run). As such, the time to complete a triathlon can range between <1 h to 17 h, depending on athlete ability (Bentley et al., 2008). Despite these differences in distance and duration, all triathlons are considered as continuous endurance events (Suriano & Bishop, 2010), requiring sustained metabolic work at intensities ranging from >80% to ~55% of peak oxygen uptake (VO_2peak) for Sprint (Bernard et al., 2003; Hausswirth et al., 2001) and Ironman (Bentley et al., 2008) distances, respectively. Diverse environmental conditions (e.g. temperature and humidity), course characteristics (e.g. currents and topography) and competitor interaction (e.g. collisions, race tactics, drafting) are commonly seen within and between triathlon competitions (Dallam et al., 2005). As a result, many studies have used triathlon simulations when attempting to examine event-specific performance and/or physiological responses in a controlled scientific environment (Bernard et al., 2003; Chan et al., 2008; Peeling et al., 2005). In addition to making physiological measurement during performance easier, it is thought that increased control of conditions should result in greater levels of reliability in any measures obtained (Sirotic & Coutts, 2008). More specifically, controlled conditions allow researchers to manipulate certain performance-related variables, such as swimming intensity (Peeling et al., 2005), cycling cadence (Bernard et al., 2003) and ambient temperature (Chan et al., 2008), in order to better establish their impact on triathlon performance (Currell & Jeukendrup, 2008). Due to the residual impact of each discipline on subsequent performance it is considered essential to include each of the three disciplines in such triathlon simulations (Peeling & Landers, 2009).

However, much research to date has focused on either swim-cycle or cycle-run simulations (Peeling & Landers, 2009), with far fewer triathlon-related studies simulating the event in its entirety (Peeling et al., 2005). Binnie et al. (2011) have recently used a simulated sprint-distance triathlon to establish the limited benefits of a warm-up to subsequent triathlon performance, associated physiological responses and psychological parameters of non-elite triathletes. However, neither Binnie et al. (2011) or any other studies to date have established the reliability of performance or physiological responses during any form of simulated triathlon. This needs addressing as a lack of reliability may undermine the findings and recommendations of simulated triathlon studies to date.

If assessment methods are to effectively measure 'real' changes in performance parameters it is essential that they are both valid and reliable (Currell & Jeukendrup, 2008). In addition to its importance in determining statistical power, the reliability of a measurement tool or performance test allows for sample size estimation in experimental studies (Atkinson & Nevill, 1998). Any test having low within-subject variation will also allow for greater precision in single performance measurement and tracking of performance changes over time (Hopkins, 2000). Indeed, if interventions are to be deemed beneficial to athletes then it is necessary for any resulting performance gains to exceed the established within-subject variation for that particular test (Smith et al., 2001). The use of triathlon simulations which have poor or unknown reliability may lead to the misinterpretation of research findings and, consequently, inappropriate recommendations being made to athletes or coaches. Therefore the aim of this study was to establish the reliability of selected performance and physiological measures during a simulated sprint-distance triathlon.

Materials and methods

Participants

Seven male triathletes (mean ± SD: age 32.6 ± 6.2 years, body mass 76.9 ± 6.0 kg) with a minimum of 2 years competitive experience volunteered to participate in this study. In accordance with Groslambert et al. (2004) and Suriano and Bishop (2010) participants were classed as 'trained triathletes' based on the maximal (mean VO_{2peak} >52 mL•kg-1•min-1) and submaximal (fixed blood lactate concentration of 4 mmol•L-1 between 85-89% VO_{2peak}) physiological characteristics of the group. All study procedures were approved by the local University Ethics committee and complied with the ethical standards of the JSC (Harriss & Atkinson, 2011). A medical history questionnaire and written informed consent were obtained from all participants. The testing schedule for each participant was arranged so that participation in competitive triathlon events was avoided for the duration of study. Participants were allowed to maintain their usual training programs (Table 1) throughout the study but were instructed to refrain from any training in the 24 h prior to each testing session. Furthermore, participants were asked to replicate dietary and fluid intake in the 24 h period preceding any testing session, using a standardized recording sheet and serving as their own control.

Table 1. Mean ± SD weekly training variables of participants during the study period (n = 7).

	h/week	km/week
Average weekly training	7.9 ± 3.3	91.0 ± 48.2
Swimming	1.9 ± 0.5	4.7 ± 3.1
Cycling	3.5 ± 2.1	60.0 ± 32.6
Running	2.0 ± 0.6	20.0 ± 6.1
Other (e.g. weight training, stretching)	0.7 ± 0.9	N/A

Experimental protocol

Each participant completed ten testing sessions in total (Figure 1), the first three of which were standardised familiarisation trials. These included first transition (T_1; 400 m swim, 250 kJ cycle), second transition (T_2; 250 kJ cycle, 2.5 km run), and complete simulated triathlon (Tri; 250 kJ cycle, 2.5 km run) sessions, with participants instructed to perform each below their perceived 'race pace' intensity to minimise physiological strain over the study period. In two subsequent sessions participants completed incremental running and cycling tests to volitional exhaustion, with each test performed at least 24 h apart and at the same time of day. The specific protocols and methods used to determine peak physiological and performance characteristics replicated those used previously in the study of sprint-distance triathletes (Bentley et al., 2003; Baldari et al., 2007). As such, both tests were preceded by a 10 min warm-up below the starting workload, which was selected based on previous results for each participant so that they would each complete tests of similar duration. During the cycle test the workload increased by 30 W every 3 min until volitional exhaustion. The maximum workload (W_{peak}) calculated as the average power output during the last 3 min of the test if the final stage was only partially completed. During the running test treadmill speed increased by 1 $km \cdot h^{-1}$ every 3 min until volitional exhaustion. If the final stage was only partially completed then maximum running speed (V_{max}) was determined using the equation of Kuipers et al. (1985): $V_{max} = V_{complete} + [(s/180) \times 1\ km \cdot h^{-1}]$, where $V_{complete}$ is the average speed achieved during the last 3 min of the test, *s* is the number of seconds completed within the final workload and 1 $km \cdot h^{-1}$ is the difference between the penultimate and final workloads. Breath by breath and heart rate (HR) data was acquired throughout each test using a portable respiratory gas analysis system (Cosmed K4b^2, Rome, Italy). A 30 s time-average was subsequently applied to this data, with VO_{2peak} and peak heart rate (HR_{peak}) calculated as the highest 30 s average value at any stage during each test. During both incremental tests capillary blood samples were collected during the final 30 s of each 3 min stage and analysed immediately for blood lactate concentration ($[BLa^{-1}]$) using a portable analyser (Lactate Pro, Kodak, Japan). The cycle workload and running speed corresponding

to a [BLa^{-1}] of 4.0 mmol·L^{-1} were both subsequently established for each participant.

Three separate simulated sprint-distance triathlon trials (750 m swim, 500 kJ cycle, 5 km run) were then completed by each participant, the first of which was performed a minimum of 72 h and maximum of 10 days after incremental testing. Triathlon trials were completed at least 72 h apart and at the same time of day, with all three trials completed within a 28 day period. The final two testing sessions were completed a minimum of 72 h and maximum of 10 days after the final simulated triathlon trial, replicating initial incremental running and cycling tests so that any training effect of triathlon trials could be identified.

During all familiarisation and simulated triathlon trials swimming was performed in a six lane, 25 m pool (water temperature ~29 °C; poolside temperature ~26 °C; relative humidity ~61%). All subsequent phases (including transition periods) were performed in an environmentally controlled room adjacent to the pool (temperature ~18°C; relative humidity ~56%). Additional air ventilation was provided by electric fans throughout all trials. Cycling was carried out on a stationary electromagnetically braked cycle ergometer (SRM; Jülich, Welldorf, Germany) fitted with participants' own pedals, whilst handle bars and racing seat were adjusted to replicate the set-up of each athlete's own bicycle. Running was performed on a motorised treadmill (LifeFitness 93T, LifeFitness Treadmills, Schiller Park, IL). Before and after each trial both the SRM ergometer and treadmill were calibrated in line with manufacturer recommendations.

Participants were instructed to complete each simulated triathlon trial (including transition periods) as quickly as possible, and performance time was started at the end of a 3 s countdown. Following the swim, participants immediately proceeded to first transition (total distance 70 m) to change into cycling footwear and for fitting of the same respiratory gas analysis system employed during initial incremental testing sessions. Participants mounted the SRM ergometer and were given 30 s to reach their preferred cycling cadence, established during familiarisation trials. Each was then required to complete 500 kJ of work as quickly as possible at a freely chosen power output. A number of previous triathlon studies have used 500 kJ as an effective estimate of the work required to complete 20 km (Binnie et al., 2011; Peeling & Landers, 2007; Peeling et al., 2005). Furthermore, the SRM ergometer provides only an estimate of speed (and therefore distance) based on the direct measurement of power output. As this power-speed relationship is dependent on factors which may not be present during indoor tests (i.e. aerodynamics, body size and topography), use of a work target is considered more conducive to better controlled performance assessments (Currell & Jeukendrup, 2008). Total work performed (kJ) was calculated and stored by the SRM powercontrol unit (version IV) as a running total. After completing the cycling phase participants dismounted the ergometer, proceeding to second transition (total distance 4 m) to change footwear and then onto the treadmill. This was programmed to start at a speed corresponding to a fixed [BLa^{-1}] of 4 mmol·L^{-1} and at a fixed gradient of 1%. It was necessary to set this initial running speed so that athletes remained unaware of their performance (i.e. running speed) throughout all trials and also so that the duration of the transition period did not extend beyond that typically observed during competition (i.e. ~2 min). As such, a running speed corresponding to a fixed [BLa^{-1}] of 4 mmol·L^{-1} was considered appropriate as this has been found to correlate (p = 0.001) with 30 min treadmill time-trial speed (McGehee et al., 2005) and also 10 km track time-trial velocity (Nicholson and Sleivert, 2001). A 30 s period was given for the treadmill (and participant) to reach this initial speed and the run phase was started. Participants were free to increase or decrease speed as desired using the treadmill controls, but remained unaware of treadmill speed throughout. The only feedback provided to participants was confirmation they had completed 250 m, 500 m and 725 m during the swim, each 10% (50 kJ) of total work during the cycle and every 20% (1 km) of total distance covered during the run. Overall performance time and sub-discipline performance times, including transition times, were recorded. Mean power output (W) was calculated from SRM data obtained for the cycle phase.

During triathlon trials participants consumed a 6.4% carbohydrate-electrolyte solution (CHO; Lucozade Sport, Glaxo SmithKline PLC) in three designated drink periods. These were scheduled during first transition and during two subsequent 30 s periods; midway through the cycling phase (250 kJ) and midway through the run phase (2.5 km). The volume of fluid intake during the first trial was replicated exactly during second and third trials (185.6 ± 45.0 mL). Previous reliability studies (Smith et al., 2001) using a similar strategy have concluded that this approach does not disrupt performance during such a trial. Furthermore, this strategy reflected the typical approach of participants during previous sprint-distance triathlons whilst allowing fluid intake to be standardised.

For each trial capillary blood was collected from the earlobe during first transition and within the final 20 kJ of each 100 kJ period of work of the cycling phase. During the run fingertip capillary blood samples were obtained within the final 200 m of each 1 km completed. No significant differences have been found between [BLa^{-1}] values obtained from the fingertip and ear during exercise (Forsyth & Farrally, 2000). Blood samples were analysed immediately for [BLa^{-1}] using a portable analyser (Lactate Pro).

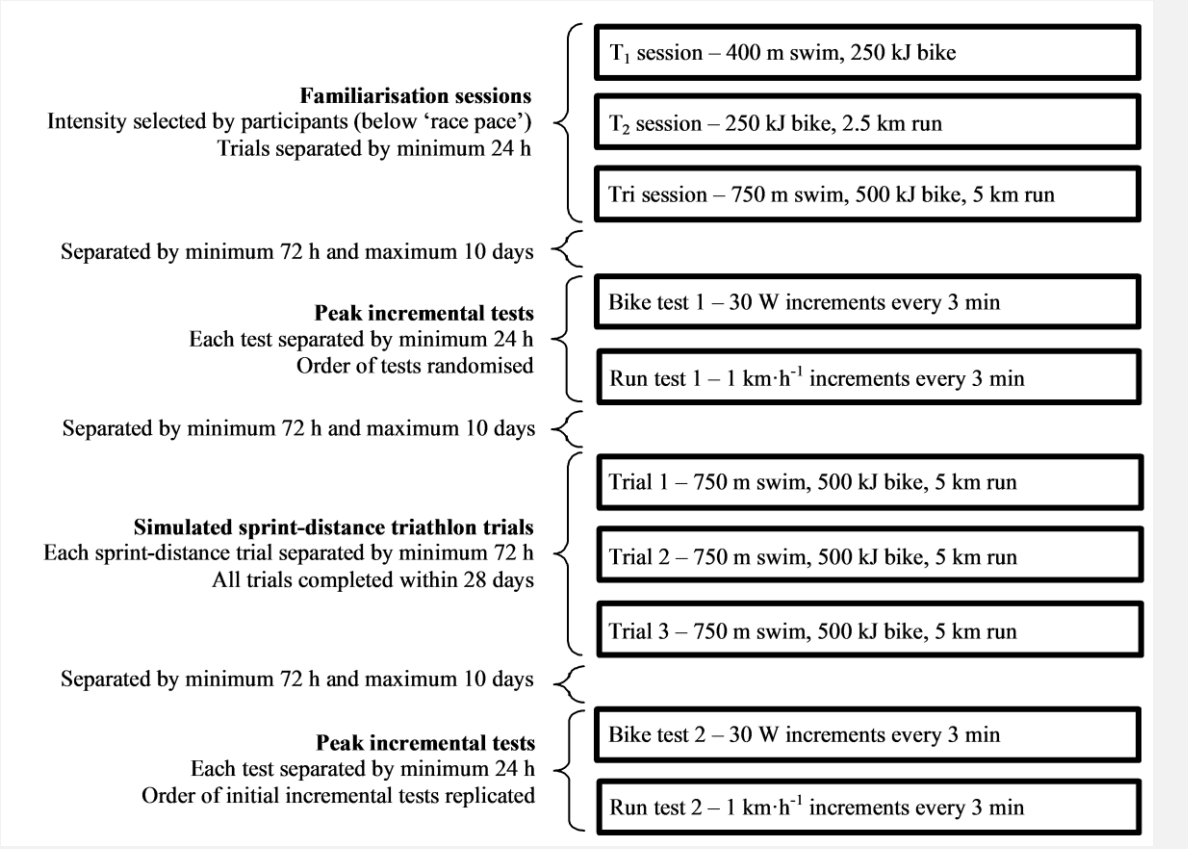

Figure 1. Summary of the experimental protocols and the periodization of trials completed by each participant. T_1; first transition, T_2; second transition, Tri; complete simulated triathlon.

Throughout all cycling and running phases oxygen uptake (VO_2), ventilation (V_E) and HR were measured continuously by Cosmed K4b^2. The gas analyser of this system was calibrated prior to each trial using ambient air and reference gases of known concentration (Cosmed, Rome, Italy), whilst volume was calibrated using a 3 L gas syringe (Cosmed, Rome, Italy). Previous studies (Dumke et al., 2006) have reported no issues in the stability of the K4b^2 calibration during performances of greater duration than the simulated triathlon trials. HR was continuously measured using a transmitter belt (Polar, Finland) integrated with the portable gas analysis system. Mean values for VO_2, V_E and HR were calculated for the cycle and run phases, and also for the combined cycle-run period, of each trial. Mean [BLa^{-1}] values were calculated for each of the swim, cycle and run phases, and also for the complete triathlon, for each trial.

Statistical analyses

Statistical procedures were performed using an excel spreadsheet (Hopkins et al., 2009) and SPSS (Version, 17, Chicago, USA). Each of the variables measured during simulated triathlon performance are reported as group mean ± standard deviation (SD). For all data the normality of test-retest differences was tested using the Shapiro-Wilks statistic, whilst heteroscedasticity was examined by calculating the Pearson's correlation coefficient between absolute differences and individual means. As both non-normality of distribution and heteroscedasticity were present in some of the data, logarithmic transformation was performed prior to further data analyses. Differences in measured variables between consecutive trials were examined using a repeated measures analysis of variance (ANOVA). As homogeneity of variance was confirmed for all variables using Maulchy's test of sphericity, post-hoc analysis assumed sphericity. Coefficient of variation (CV), intraclass correlation coefficient (ICC; model 3,1) and ratio measures for 95% limits of agreement (LoA) were then calculated. Differences in incremental test results before and after the period of simulated triathlon assessment were assessed by means of a paired samples t test. Results for all tests were considered significant at $p < 0.05$.

Results

Table 2 reports the mean values for all performance and physiological variables measured during each of the simulated triathlon trials. As such, the mean intensity of the cycle phase across trials corresponded to 89.6 ± 3.5% HR_{peak}, 82.1 ± 6.0% VO_{2peak} and 68.2 ± 7.2% $W_{peak,}$ whilst mean run intensity across trials corresponded to 91.9 ± 1.9% HR_{peak}, 89.7 ± 4.9% VO_{2peak} and 87.5 ± 3.0% V_{peak}. Reliability measures for performance and physiological variables across simulated triathlon trials are presented in Table 3.

Table 2. Mean ± SD values for performance and physiological variables measured during each simulated triathlon trial (n = 7).

	Trial 1	Trial 2	Trial 3
Performance measures			
Total time (min:s)	77:37 ± 06:41	78:22 ± 08:59	78:47 ± 09:56
Swim time (min:s)	12:24 ± 01:22	12:19 ± 01:23	12:19 ± 01:25
T_1 time (min:s)	02:26 ± 00:14	02:26 ± 00:09	02:23 ± 00:13
Cycle time (min:s)	39:34 ± 04:54	40:46 ± 07:06	41:08 ± 08:16
Cycle power (W)	212.8 ± 25.7	208.7 ± 35.4	208.1 ± 37.5
T_2 time (min:s)	01:15 ± 00:17	01:13 ± 00:15	01:17 ± 00:16
Run time (min:s)	21:59 ± 02:19	21:38 ± 01:59	21:39 ± 02:09
Physiological measures			
Triathlon [BLa^-] ($mmol \cdot L^{-1}$)	7.6 ± 0.9	7.2 ± 1.3	7.1 ± 1.1
Swim [BLa^-] ($mmol \cdot L^{-1}$)	6.5 ± 0.7	6.5 ± 1.0	6.4 ± 1.5
Cycle [BLa^-] ($mmol \cdot L^{-1}$)	7.5 ± 1.5	7.0 ± 1.8	7.1 ± 2.0
Run [BLa^-] ($mmol \cdot L^{-1}$)	8.0 ± 0.6	7.4 ± 1.3	7.4 ± 0.7
Cycle VO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$)	44.1± 4.1	44.4 ± 5.1	44.1 ± 5.5
Run VO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$)	49.4 ± 6.1	50.2 ± 5.0	49.2 ± 6.7
Cycle-Run VO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$)	46.2 ± 4.8	46.6 ± 5.0	46.2 ± 6.1
Cycle V_E ($L \cdot min^{-1}$)	108.6 ± 9.8	107.1 ± 18.9	106.5 ± 13.3
Run V_E ($L \cdot min^{-1}$)	127.2 ± 12.1	127.2 ± 14.7	128.5 ± 17.7
Cycle-Run V_E ($L \cdot min^{-1}$)	116.4 ± 10.0	115.0 ± 16.0	115.7 ± 14.4
Cycle HR ($beat \cdot min^{-1}$)	157.5 ± 5.5	155.1 ± 5.8	155.5 ± 4.5
Run HR ($beat \cdot min^{-1}$)	164.0 ± 2.8	165.6 ± 5.5	166.4 ± 2.7
Cycle-Run HR ($beat \cdot min^{-1}$)	161.9 ± 6.9	159.8 ± 4.9	161.1 ± 4.9

T_1: first transition, T_2: second transition, [BLa^{-1}]: blood lactate concentration, VO_2: oxygen uptake, V_E: ventilation, HR: heart rate.

Although overall triathlon performance was slightly quicker during trial 1 compared to trial 2, and likewise during trial 3, these differences were not statistically significant. Indeed, ANOVA *F* scores and *p* values indicate there were no significant differences in any performance or physiological variable measured across trials. When comparing ratio LoA for trials 1-2 and 2-3, similar values were observed for all performance measures except for second transition time (0.972 */÷ 1.104 versus 1.051 */÷ 1.240). CV for all performance measures was higher for trials 1-2 when compared to trials 2-3, with the exception of second transition time (3.5% versus 8.1%). Combined time for first and second transitions represented ~0.2% of total performance time, with a combined CV of 5% ([95% CI] 3.2 - 11.4). Of all the physiological variables measured [BLa^{-1}] presented the highest values for CV and ratio LoA, for both trials 1-2 and 2-3. Specifically, mean [BLa^{-1}] during the cycle phase of simulated triathlon showed the greatest CV (17.3%) and ratio LoA (0.929 */÷ 1.555). Table 4 shows the results obtained during both periods of incremental running and cycle testing. For all parameters measured during incremental testing no significant differences were found between initial results and those obtained after the period of simulated triathlon assessment.

Discussion

The main finding of this study is that, following initial familiarisation, performance during simulated sprint-distance triathlon shows high levels of reliability in trained male triathletes. As such, this is the first study to our knowledge to have examined the reliability of simulated triathlon performance, and associated physiological responses, regardless of event distance. All performance measures (except transitions) displayed a CV <10% and ICC >0.8, which are commonly used reliability criteria in sports science research (Atkinson et al., 1999). Furthermore, CV's for total performance time across all trials were within the typical range (<5%) for endurance performances of similar duration (Currell & Jeukendrup, 2008), and are comparable to elite Olympic-distance competition (1.9%) (Paton & Hopkins, 2005). Reproducibility for most physiological measures was high, with all but 5 variables displaying a CV <10% and ICC >0.8, following initial familiarisation. Although CV's for some [BLa^-] values were above this range, the recommended 'acceptable' CV for [BLa^{-1}] is <15% (Gore, 2000). Furthermore, variables with ICC values between 0.6 and 0.8 (cycling and running HR; cycling and cycle-run V_E; swimming, cycling and running [BLa^{-1}]) or between 0.4 and 0.6 (cycling HR; running [BLa^{-1}]) are still considered to have either 'substantial' or 'moderate' agreement between trials, respectively (Landis & Koch, 1977).

Performance time CV's within swimming and running phases of simulated triathlon are lower than reported during elite triathlon competition (Paton & Hopkins, 2005), with values in agreement with studies of the individual modalities (Stewart & Hopkins, 2000; Laursen et al., 2007). These findings likely reflect the greater stability of conditions during simulated triathlon, supporting the use of this test to effectively examine performance and/or physiological responses during triathlon. CV's for performance time and mean power output during the cycling phase of simulated triathlon (3.9-5.7%) are higher than those reported during cycling performance alone (Smith et al., 2001; Palmer et al., 1996). However, cyclists have been shown to pedal more effectively and economically compared to triathletes (Candotti et al., 2007), resulting in superior cycling time-trial performance (Laursen et al., 2003).

Table 3. Reliability measures (including 95% confidence intervals) of performance and physiological variables from three simulated triathlon trials (n = 7)

	Trials 1-2						Trials 2-3						Repeated measures ANOVA	
Parameters	Mean	CV	CI (%)	Ratio LoA	ICC	CI	Mean	CV	CI (%)	Ratio LoA	ICC	CI	*F*	*p*
Performance measures														
Total time (min:s)	77:59	2.7	(1.7 - 6.0)	1.008 */÷ 1.077	0.920	(0.610 - 0.986)	78:34	2.3	(1.5 - 5.1)	1.004 */÷ 1.064	0.959	(0.783 - 0.993)	1.182	.369
Swim time (min:s)	12:21	1.6	(1.0 - 3.5)	0.993 */÷ 1.044	0.986	(0.921 - 0.998)	12:19	1.1	(0.7 - 2.3)	1.000 */÷ 1.030	0.994	(0.963 - 0.999)	.135	.876
T_1 time (min:s)	02:26	9.7	(6.2 - 22.6)	1.004 */÷ 1.296	0.279	(-0.823 - 0.533)	02:25	9.2	(5.8 - 21.4)	0.978 */÷ 1.280	-0.203	(-0.796 - 0.588)	.166	.850
Cycle time (min:s)	40:10	5.6	(3.6 - 12.8)	1.025 */÷ 1.163	0.841	(0.332 - 0.971)	40:57	3.9	(2.5 - 8.9)	1.006 */÷ 1.113	0.947	(0.725 - 0.991)	.225	.805
Cycle power (W)	210.75	5.7	(3.6 - 12.9)	0.976 */÷ 1.165	0.837	(0.319 - 0.970)	208.37	3.9	(2.5 - 8.7)	0.995 */÷ 1.111	0.949	(0.734 - 0.991)	.235	.797
T_2 time (min:s)	01:14	3.5	(2.3 - 8.0)	0.972 */÷ 1.104	0.968	(0.826 - 0.994)	01:15	8.1	(5.2 - 18.8)	1.051 */÷ 1.240	0.876	(0.446 - 0.978)	1.134	.382
Run time (min:s)	21:48	1.3	(0.8 - 2.9)	0.985 */÷ 1.037	0.978	(0.881 - 0.996)	21:39	1.2	(0.7 - 2.6)	1.000 */÷ 1.033	0.981	(0.894 - 0.997)	2.291	.182
Physiological measures														
Triathlon [BLa^{-1}] ($mmol \cdot L^{-1}$)	7.4	.1.3	(7.1 - 26.6)	0.931 */÷ 1.345	0.625	(-0.146 - 0.924)	7.1	7.2	(4.6 - 16.5)	1.004 */÷ 1.211	0.855	(0.374 - 0.973)	.833	.479
Swim [BLa^{-1}] ($mmol \cdot L^{-1}$)	6.5	7.3	(4.7 - 16.8)	0.994 */÷ 1.216	0.763	(0.122 - 0.955)	6.5	7.5	(4.8 - 17.3)	0.969 */÷ 1.223	0.876	(0.443 - 0.977)	1.738	.254
Cycle [BLa^{-1}] ($mmol \cdot L^{-1}$)	7.3	.7.3	10.8 - 42.0)	0.929 */÷ 1.555	0.669	(-0.071 - 0.934)	7.0	9.0	(5.7 - 20.9)	1.005 */÷ 1.270	0.917	(0.598 - 0.985)	.406	.683
Run [BLa^{-1}] ($mmol \cdot L^{-1}$)	7.7	9.6	(6.1 - 22.4)	0.922 */÷ 1.290	0.540	(-0.269 - 0.902)	7.4	11.0	(7.0 - 26.0)	0.999 */÷ 1.337	0.414	(-0.414 - 0.876)	.943	.441
Cycle $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	44.2	4.2	(2.7 - 9.4)	1.006 */÷ 1.120	0.858	(0.385 - 0.974)	44.3	4.9	(3.1 - 12.6)	1.004 */÷ 1.143	0.837	(0.224 - 0.975)	.000	1.000
Run $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	49.8	4.0	(2.5 - 9.0)	1.018 */÷ 1.114	0.862	(0.396 - 0.975)	49.7	3.7	(2.3 - 9.4)	0.991 */÷ 1.107	0.886	(0.397 - 0.983)	.065	.938
Cycle-Run $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	46.4	3.7	(2.4 - 8.4)	1.009 */÷ 1.106	0.874	(0.438 - 0.977)	46.4	3.8	(2.4 - 9.6)	1.001 */÷ 1.110	0.892	(0.422 - 0.984)	.022	.979
Cycle HR ($beat \cdot min^{-1}$)	156.8	2.6	(1.7 - 5.8)	0.983 */÷ 1.074	0.391	(-0.437 - 0.860)	155.3	1.9	(1.2 - 4.8)	1.004 */÷ 1.055	0.692	(-0.130 - 0.950)	.296	.754
Run HR ($beat \cdot min^{-1}$)	164.9	1.3	(0.8 - 3.8)	1.001 */÷ 1.037	0.784	(-0.076 - 0.975)	166.0	1.8	(1.1 - 5.3)	1.007 */÷ 1.051	0.737	(-0.185 - 0.969)	.507	.626
Cycle-Run HR ($beat \cdot min^{-1}$)	159.8	1.0	(0.6 - 3.0)	0.989 */÷ 1.029	0.892	(0.293 - 0.988)	159.2	1.9	(1.1 - 5.5)	1.003 */÷ 1.053	0.645	(0.349 - 0.956)	.429	.670
Cycle $\dot{V}_E$ ($L \cdot min^{-1}$)	107.9	8.6	(5.5 - 20.0)	0.977 */÷ 1.257	0.682	(-0.048 - 0.937)	106.8	7.4	(4.6 - 19.2)	1.028 */÷ 1.220	0.787	(0.080 - 0.967)	.025	.975
Run $\dot{V}_E$ ($L \cdot min^{-1}$)	127.2	3.1	(2.0 - 7.0)	0.998 */÷ 1.089	0.897	(0.521 - 0.982)	127.8	4.4	(2.7 - 11.2)	0.998 */÷ 1.128	0.860	(0.301 - 0.979)	.407	.683
Cycle-Run $\dot{V}_E$ ($L \cdot min^{-1}$)	115.7	5.5	(3.5 - 12.6)	0.984 */÷ 1.161	0.770	(0.138 - 0.956)	115.4	4.6	(2.8 - 11.6)	1.019 */÷ 1.132	0.884	(0.390 - 0.983)	.216	.812

T_1: first transition, T_2: second transition, [BLa^{-1}]: blood lactate concentration, $\dot{V}O_2$: oxygen uptake, $\dot{V}_E$: ventilation, HR: heart rate, CV: coefficient of variation, CI: 95% confidence intervals, ICC: intraclass correlation coefficient, LoA: limits of agreement.

Table 4. Mean ± SD values obtained from incremental cycling and running tests performed before (pre-TRI) and after (post-TRI) simulated sprint-distance triathlon testing period.

	Pre –TRI	Post-TRI	Student's *t*-test	
			t	*p*
Peak cycling values				
$\dot{V}O_{2peak}$ ($L \cdot min^{-1}$)	4.2 ± 0.4	4.5 ± 0.7	-2.081	.173
$\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	54.1 ± 6.0	56.4 ± 5.5	-2.194	.160
W_{peak} (W)	307.0 ± 19.5	317.6 ± 25.4	-.108	.918
W_{peak} ($W \cdot kg^{-1}$)	4.0 ± 0.4	4.1 ± 0.3	-.114	.913
W_{4mmol} (W)	241.0 ± 15.3	239.0 ± 25.1	-.203	.846
HR_{peak} ($beat \cdot min^{-1}$)	175 ± 6	174 ± 5	.138	.895
Peak running values				
$\dot{V}O_{2peak}$ ($L \cdot min^{-1}$)	4.3 ± 0.5	4.7 ± 0.7	-2.396	.139
$\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	55.5 ± 3.9	59.4 ± 5.8	-2.817	.106
V_{peak} ($km \cdot h^{-1}$)	15.9 ± 1.2	16.1 ± 1.4	-1.369	.220
V_{4mmol} ($km \cdot h^{-1}$)	13.6 ± 1.0	13.8 ± 1.2	-.485	.645
HR_{peak} ($beat \cdot min^{-1}$)	182 ± 6	182 ± 5	-.101	.923

$\dot{V}O_{2peak}$: peak oxygen uptake, W_{peak}: peak aerobic power, W_{4mmol}: power output at fixed [BLa^{-1}] of 4 $mmol \cdot L^{-1}$, HR_{peak}: peak heart rate, V_{peak}: peak running velocity, V_{4mmol}: speed at a fixed [BLa^{-1}] of 4 $mmol \cdot L^{-1}$.

As such, it is expected that 'less able' athletes (i.e. triathletes) perform with relatively less reliability compared to higher calibre athletes (i.e. cyclists) in the same event (Paton & Hopkins, 2005). Similarly, it is possible that 'non-elite' triathletes used in the present study may show greater performance variability compared to their 'elite' counterparts. However, performance time and power output (%W_{peak}) during this phase of the simulated triathlon are representative of previous sprint-distance simulations (Bernard et al., 2003; Binnie et al., 2011), and are above the range reported during elite Olympic-distance competition (~60-63%) (Bernard et al., 2009). Increased variability during the cycle phase of triathlon (versus isolated cycling) may therefore be due to other factors, such as residual fatigue mechanisms associated with prior swimming (Peeling et al., 2005; Peeling & Landers, 2009) or the complex process of work-rate regulation in anticipation of the subsequent running phase (Hausswirth et al., 2010).

There are currently a lack of published reliability data for HR, respiratory and [BLa^{-1}] measurement during simulated triathlon. The greater variability observed in physiological responses versus performance measures is expected during self-paced performance simulations so should not undermine the simulated triathlon as a reliable performance test. Indeed, this variability is, to some extent, an artefact of the random error introduced by the self-selected intensity during each simulated triathlon trial (Sirotic & Coutts, 2008). The greater variability of [BLa^{-1}] may also be exacerbated by inconsistencies in the timing of blood sampling between trials, which may occur as a result of the spontaneous changes in intensity throughout self-paced performance assessments such as the simulated sprint-distance triathlon. Despite these points, physiological responses observed in the present study are comparable to those reported previously for both elite and non-elite triathletes completing similar triathlon simulations (Hausswirth et al., 2001; Binnie et al., 2011).

As this is the first study to report on the reliability of simulated triathlon performance and associated physiological responses, it has a number of important practical implications for future research studies using this method of performance assessment. By applying the ratio LoA from trials 2-3 (Table 2) to the nomogram derived by Atkinson & Nevill (2001) an estimated sample size of between 5 and 10 is needed if simulated triathlon studies are to detect a 10% change in all performance parameters, except for transition times (statistical power = 0.90), whilst a 5% change may be detected in all performance parameters (excluding transition times) with an estimated sample size of 20. Likewise, an estimated sample size of 10 would be required to detect a 5% change in mean HR and $\dot{V}O_2$ during simulated triathlon performance, whilst the detection of a 10% change in mean [BLa^{-1}] across a complete simulated triathlon would require an estimated sample size of 15 (Atkinson & Nevill, 2001). The present results also highlight the need for a number of physiological parameters (e.g. HR, $\dot{V}O_2$, V_E, [BLa^{-1}]) to be measured during simulated triathlon performance, rather than relying on individual parameters which may have relatively high within-subject variability. Furthermore, the familiarisation prescribed in the present study appears to have been adequate as no significant differences were observed in any of the performance or physiological variables measured across simulated triathlon trials. However, a trend was still apparent for greater reliability between trials 2-3 when compared to trials 1-2 (Table 3), particularly in CV values for performance measures. Based on this observation it may be advisable for future simulated triathlon studies to include a 'maximally' paced triathlon trial (i.e. trial 1) within the initial familiarisation period, in order to minimise any learning effects.

In conclusion, for trained male triathletes, performance during simulated triathlon shows a high level of reliability comparable to endurance performances of similar duration. A majority of physiological responses measured during simulated triathlon displayed high reproducibility (CV <10% and ICC >0.8), whilst all remaining measures showed 'substantial', 'acceptable' or 'moderate' agreement between trials (CV < 15% and ICC 0.4-0.8). The simulated triathlon therefore provides a reliable tool

with which to assess changes in performance and associated physiological responses of short-distance triathletes. Furthermore, the results of this study suggest that future simulated triathlon research should incorporate a range of physiological measures and should also consider the reliability of this performance test when interpreting results. This should allow for more rigorous detection of genuine changes between experimental trials and the subsequent provision of appropriate recommendations to triathletes and coaches based on this evidence.

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