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The reliability of physiological responses obtained during a simulated long distance triathlon laboratory test.

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Abstract

The aim of this study was to investigate the reliability of a newly developed long distance (LD) simulated triathlon for testing physiological and performance changes in LD triathletes. Ten trained LD triathletes (mean ± standard deviation: age 34.1 ± 5.0 years, body mass 69.07 ± 13.89 kg) completed two separate trials of a simulated LD triathlon consisting of a 1500 m swim, a 60 minute cycle at 60% of power at VO_{2max} and a 20 minute run at 70% of velocity at VO_{2max}. Physiological (oxygen consumption, energy cost, blood lactate and heart rate) and performance (time, power and rating of perceived exertion) variables were measured throughout the simulated LD triathlon. Coefficient of variations (CV %) and intra class correlation coefficients (ICC) were calculated to determine reliability. The current study displayed a high level of reliability, with moderate to excellent ICC measurements for physiological and performance variables (ICC 0.62 – 0.99). All physiological variables demonstrated CV values < 10% except cycling and running blood lactate (26.1% and 19.2% respectively). In conclusion, the newly developed LD simulated triathlon has a high level of task representation for LD triathletes and can accurately assess physiological changes in a research setting.

Keywords: multisport, endurance, testing, representative task

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Introduction

Triathlon competition is dependent on the consecutive completion of swimming, cycling and running with transition phases between each discipline. The economy of movement, pacing and performance of each discipline within a triathlon is highly dependent on the distance of the race. Event duration and completion times range from a ‘sprint’ short distance (SD; 750 m swim, 20 km cycle and 5 km run) race, (taking 55 minutes for professional and up to 2 hours for recreational athletes to complete), to long distance (LD), classified as any event longer than an Olympic distance triathlon (OD; 1500 m swim, 40 km cycle and 10 km run). The most common forms of LD triathlon are known as a ‘full iron’ distance (3.8 km swim, 180 km cycle and 42.2 km run) and ‘half iron’ distance (1.9 km swim, 90 km cycle and 21.1 km run) with completion times varying from 3 hours 40 minutes to 17 hours depending on athlete ability.

Recent research in sport science has emphasised the importance of investigating individual performance by undertaking research testing which represents that of the competition setting (Piggott et al. 2019). Performance assessments must demonstrate a relationship between the assessments undertaken and the performance event that replicate the behaviours of athletes in training and/or competitions (Hopkins et al. 1999). Ideally, assessments and tests should have ‘high task representation’, meaning that tests utilised are truly reflective of the individual during a task which replicates the race setting (Piggott et al. 2019). In an ideal research environment, performance and physiological changes of athletes should be assessed during the sporting events (Hopkins et al. 1999). In SD triathlon racing, the shorter race durations enable the replication or utilisation of the sporting events as a feasible option to measure athlete performance and physiology for research. Due to the nature of LD triathlon, it is not logistically feasible to use the sporting event to accurately determine performance or physiological changes in athletes for research purposes. Further, the completion of LD triathlon creates substantial muscle damage and inflammation in LD triathletes which requires at least 2 – 3 weeks of active recovery before gradually recommencing training (Suzuki et al. 2006). The use of LD triathlon events in research is not possible to repeat on numerous occasions to avoid such stressors in athletes. The variability in performance measured during events lasting 3.5 -17 hours can also arise from environmental conditions such as weather or course terrain. These external and individual factors of LD triathlon may impact directly on competition results therefore decreasing the reliability of research results. Due to the lack of feasibility of utilising a LD triathlon as an outcome measure in research, there is a need to establish a reliable test which can be utilised to determine physiological changes vital to performance in LD triathletes.

Workload and physical stress from each triathlon discipline influence performance on the succeeding discipline, likely impacting overall performance (Guezennec et al. 1996; Millet et al. 2000; Peeling and Landers 2009). Research investigating the impact of swimming performance and pacing during simulated triathlons demonstrates consequential negative impacts on the ensuing cycle performance (Peeling and Landers 2009). Additionally, triathletes who undertook a cycle workout prior to a run demonstrated decreased running economy (RE) by 1.6 – 11.6% (Etxebarria et al. 2014; Millet et al. 2000). Furthermore, RE was significantly reduced following completion of a consecutive swim and cycle when compared to an isolated run session (Guezennec et al. 1996; Hausswirth et al. 1996). It is hypothesised that the swim and/or cycle disciplines could result in ventilatory muscle fatigue, dehydration, metabolic changes or biomechanical alterations which contribute to reductions in RE (Hausswirth et al. 1996; Millet et al. 2000).

Since execution of the preceding discipline within triathlon appears to negatively impact overall performance, it is essential to account for this in the development of novel assessment methods for physiological outcomes in triathlon research (Etxebarria et al. 2014). Field tests that focus on one discipline of triathlon alone would be classified as having 'low representative task design' (Piggott et al. 2019). Assessments that measure isolated performance and physiology in a single discipline of triathlon may be of some use to help predict overall performance in OD racing, however current research would suggest this is not sufficient to accurately predict performance in LD triathlon events (Marongui et al. 2013). The lack of representative task design and decreased validity of using isolated running tests to predict LD triathlon performance may be due to absence of fatigue when analysing isolated running compared with running performed after a pre-fatiguing swim and cycle (Marongui et al. 2013). Studies that examined both physiological and performance changes in triathlon have acknowledged the need for high representative task design tests and have endeavoured to examine these changes through simulated triathlons, swim-cycle or cycle-run tests (Guezennec et al. 1996; Hausswirth et al. 1996; Millet et al. 2000; Peeling et al. 2005). Whilst these studies have attempted to address representative task design within simulated tests, many did not include a pre-fatiguing swim, an additional component known to negatively impact performance and physiology of the subsequent cycle and run activities. Furthermore, no studies have included LD specialist triathletes or designed simulated triathlons that would replicate LD specific demands during testing. Moreover, whilst research has utilised simulated triathlons or consecutive triathlon disciplines to test athlete performance and physiology, only two studies to the best of our knowledge have examined the reliability of performance variables (total time, pace and power) and physiological responses (economy of movement, blood lactate (BLa) and heart rate (HR)) during a simulated triathlon or run-bike-run (RBR) (Taylor 2012; Vleck et al. 2012). One of these studies examined the reliability of a SD simulated triathlon, with results suggesting a high level of reliability of the key physiological variables (economy measurements and HR) (CV <10% and ICC > 0.8). In a similar manner, the reliability of a RBR in SD triathletes displayed high reliability of most physiological variables (economy of movement, BLa and HR) (CV < 20% and ICC > 0.8) (Vleck et al. 2012). However, there is selection bias limitation for implementing the results from the previous research to LD specialist triathletes, as both studies recruited specialised SD triathletes and performed tests that were completed over distances reflective of a SD event.

Racing, training and physiological factors vary largely amongst triathlon distance specialists (Ofoghi et al. 2016; Sleivert and Rowlands 1996; Vleck et al. 2010). In SD racing, triathletes demonstrate large variability in power throughout the cycle discipline, however it has even been stated that cycling performance during OD triathlon has little to no influence on the overall outcome of the race (Ofoghi et al. 2016). In contrast, the absence of drafting in LD triathlon events increases the importance of cycling on overall performance with the cycling discipline having the greatest influence on the overall outcome of LD racing (Ofoghi et al. 2016). Additionally, it is recommended that LD triathletes generally adopt more even pacing during the cycle and run disciplines to accommodate for glycogen depletion, neuromuscular fatigue, psychological factors and mental fatigue which accompany longer distance triathlon when compared to SD racing (Abbiss et al. 2006; Laursen 2011; O'Toole et al. 1989; Wu et al. 2015). As a result, LD specialists spend significantly more time in training on 'long' cycles and runs compared to OD and SD specialists (Vleck et al. 2010). Due to the nature of differences in training loads and race strategies in specialist triathletes, it would be expected that these athletes would differ in their physiological performance during an event specific simulated triathlon conducted in the laboratory (Bentley et al. 2002; Vleck et al. 2012; Vleck et al. 2010). It is therefore necessary to test triathletes at race relevant distances and analyse physiological improvements in an assessment with a high representative task design reflecting distances similar to their chosen event speciality (Hopkins et al. 1999; Piggott et al. 2019).

In sport science, specifically designed assessments for sports such as triathlon are recommended to have high representative task design and known reliability to enable coaches and scientists to test training interventions and monitor athletes progress (Hopkins 2000; Hopkins et al. 1999; Taylor 2012). No study to the best of our knowledge has investigated the reliability of a simulated triathlon with a high level of task representation appropriate for testing physiological changes in LD triathletes. Therefore, the aim of this study was to establish the reliability of physiological measures collected during a simulated triathlon replicating a shortened version of a LD triathlon, which is considered appropriate for testing LD specialists.

Methods

Ten triathletes comprising of nine trained (Suriano and Bishop 2010) (male = 6, female = 3) and one elite male volunteered to participate in this study. Participants were from local triathlon clubs in Perth, Western Australia. All participants had completed at least one LD triathlon in the last 12 months. A sample size of 10 participants was selected based on previous research to detect a 10% change in all parameters (Taylor 2012). Approval to conduct this study was granted by the Universities Human Research Committee by The University of Notre Dame, Australia (106101F).

Participants completed both a running and cycling graded exercise test (GXT) to determine their velocity at VO_{2max} (vVO_{2max}) and power at VO_{2max} (wVO_{2max}). A StarTrack treadmill was used to complete the run GXT with the inclination set to 1 % (Jones and Doust 1996). Participants completed a 10-minute self-paced warm-up to become accustomed to the treadmill. Participants then commenced the GXT at 8 $km \cdot h^{-1}$, with the speed increasing by 1 $km \cdot h^{-1}$ every minute until the participant was unable to maintain the intensity or terminated the test due to volitional exhaustion (Vikmoen et al. 2017). Participants completed the cycle GXT on a WattBike Pro. Participants again completed a 10 minute self-paced warm-up then commenced the test at 100 watts (W), with intensity increasing by 40 W every 3 minutes until the participant was unable to maintain the intensity or terminated the test due to volitional exhaustion (Peeling et al. 2005). Throughout the duration of each test, breath by breath and HR data was acquired using a Moxus modular VO_2 system. Participant's VO_{2max} was defined as the highest 60 second value reached during the GXT. The vVO_{2max} and wVO_{2max} were determined as the velocity or power sustained for at least 60 seconds at which VO_{2max} was reached (Millet et al. 2002). Participants completed the run GXT first with the cycling GXT a minimum of 2 days and maximum of 7 days later.

Each simulated triathlon trial consisted of a 1500 m swim at 85% of the participants perceived maximal effort (Peeling et al. 2005), transition 1 (T1), a 60-minute cycle at 60% of wVO_{2max}, transition 2 (T2), and a 20-minute run at 70% of vVO_{2max} completed consecutively. All swims were completed in the participants racing suit in an outdoor heated 50 m pool (27°C). Immediately after concluding the swim, T1 commenced which involved participants being transported by car from the swimming pool to an indoor environmentally controlled laboratory (25°C, 44% relative humidity) with additional air ventilation from fans to maintain these conditions throughout the simulated triathlon. Participants then put on their cycling shoes and then completed a 60-minute stationary cycle at 60% of wVO_{2max} at a self-selected cadence. The WattBike was set into a position that replicated the participants' personal bicycle set up and was recorded and repeated for each trial. Participants were instructed to hold their pre-set power for the duration of their ride.

Upon completion of the 60-minute cycle, participants completed T2, which consisted of each participant changing from their cycling to running shoes and commencing the run on the treadmill. Participants then completed a 20-minute run on a treadmill (StarTrack) set at a pace equivalent to 70% of their vVO_{2max} with the incline set to 1% (Jones and Doust 1996).

A Moxus Modular VO_2 system was used to measure gas exchange every 15 seconds, allowing the calculation of pulmonary ventilation (V_E), oxygen uptake (VO_2), carbon dioxide expired (VCO_2) and respiratory exchange ratio (RER) with subjects breathing through Hans Rudolph one-way valve head piece. Gas exchange measurements were taken during three stages of the cycle discipline (minutes 7 – 12, 27 – 32 and 52 – 57) and at two stages of the run (minutes 5 – 10 and 15 – 20). Rating of perceived exertion (RPE) using a 10-point RPE Scale (Borg et al. 1987) and HR were measured immediately post the swim and during each gas exchange measurement period. A capillary blood sample was taken from the fingertip at the end of the three gas exchange measurement stages during the cycle and once during the run to determine BLa (using an Accutrend plus (Accusport, Boehringer Mannheim)) was below $4 mmol \cdot l^{-1}$. Participants RER was monitored to ensure it was below 1 during testing to maximise economy measurements by avoiding the VO_2 slow component. Participants wore the same attire during each of the simulated triathlons. A food and training questionnaire were completed by each participant 48 hours prior to their initial simulated triathlon with all participants required to replicate training, food and fluid intake prior to subsequent simulated triathlon. Participants were only allowed to consume water ad libitum during the simulated triathlon. All participants completed their trials at the same time of day to control for circadian variation in physiology. The initial simulated triathlon served as a 'familiarisation' trial for participants and was completed within two weeks of the initial GXT completion. The participants then completed the following two trials with a minimum of 3 days and a maximum of 8 days apart.

Table 1. Mean ± σ values for performance variables measured during the 1500m swim of simulated triathlon.

	Trial 1	**Trial 2**
Swim		
Time (mm:ss)	27:09 ± 2:37	27:02 ± 2:47
RPE	5 ± 1.5	5.2 ± 1.7
Transition time		
T1 (mm:ss)	6:32 ± 1:05	6:40 ± 1:02
T2 (s)	43.7 ± 21.2	49.5 ± 18.8
OA RPE	4.8 ± 1.7	4.8 ± 1.7

T_1: first transition, T_2: second transition, (mm:ss): minutes:seconds, (s): seconds, RPE: Rating of Perceived Exertion, OA: overall

Economy calculations

Gas exchange measurements during the final minute of each measuring sample time period was analysed to determine VO_2 in ml·kg$^{-0.75}$·km^{-1} and ml·km^{-1}. Appropriate allometric scaling exponent (0.75) was used to account for the non-linearity associated with oxygen uptake response to differences in body mass (Curran-Everett 2013). VO_2 and VCO_2 were used to calculate energy cost (EC). Nonprotein respiratory quotient equations (Peronnet and Massicotte 1991) were used to estimate substrate utilisation (g·min^{-1}). The energy derived from each substrate was then calculated by multiplying fat and carbohydrate usage by 9.75 kcal and 4.07 kcal, respectively, reflecting the mean energy content of the metabolised substrates during moderate to high intensity exercise (Jeukendrup and Wallis 2005). The EC was quantified as the sum of these values, expressed in kcal·kg$^{-0.75}$·km^{-1} and kcal·km^{-1}. VO_2 during cycling was measured as the power produced in W divided by the volume of oxygen used to produce the power in litres per minute per kilogram (W·L·min^{-1}·kg^{-1}).

Statistical analysis

Means and standard deviations (σ) were calculated for all measures across the two simulated triathlon trials. Differences in measured variables between consecutive trials was examined using a paired student's t-test with statistical significance set at $p < 0.05$. The typical error (TE) associated with reliability measurements was calculated for each variable as the (σ) of the difference in each of the trials divided by √2 (Hopkins 2000). Coefficients of variation (CV%) and intra-class correlation coefficients (ICC) with 95% confidence intervals (CI) after fitting a linear mixed model with subject and day as random effects were calculated to determine between trial reliability of the simulated triathlons (Hopkins 2000). The following criteria were used to classify ICC outcomes: poor = <0.50; moderate = 0.51 – 0.75; good = 0.76 – 0.90; and excellent = > 0.90 (Koo and Li 2016). Mean differences between trials were also calculated to demonstrate the reliability of measures. Statistical analyses were performed using Stata (v.14.2, Texas, USA).

Results

The participants mean VO_{2max} was 56.6 ± 8.43 ml·kg^{-1}·min^{-1} and 55.2 ± 7.26 ml·kg^{-1}·min^{-1} for the run and cycle respectively. Their mean age and body mass were 34.1 ± 5.0 years and 69.07 ± 13.89 kg respectively. All variables (mean ± σ) measured throughout each of the simulated triathlon trials are displayed on Tables 1, (swim) 2 (cycle) and 3 (run). All mean ± σ were calculated from the last two simulated trials as the initial trial was considered as a 'familiarisation' trial for all participants to become accustomed with testing procedures.

The mean differences between trials and reliability measures (ICC, CV and typical error (TE)) of all variables are displayed on Table 4. Mean differences and reliability measurements presented on Table 4 are calculated from the average of all samples taken over the duration of the individual simulated triathlon trials.

Across the two trials, swim times displayed excellent measures of reliability [ICC 0.96 (95% CI 0.88 - 0.99), CV < 1.9%] (Table 4). Physiological measurements of cycling (CE and HR) demonstrated moderate reliability across the two trials [ICC 0.62 (95% CI 0.40 – 0.83), CV 3.8% and ICC 0.65 (95% CI 0.40 – 0.84), CV 3.41% respectively] (Table 4). Cycle physiological variables displayed lower between trial reliability than swim and run variables (Table 4). Run physiological measurements including EC (kcal·km$^{-0.75}$), EC·km^{-1} (kcal·kg$^{-0.75}$·km^{-1}), VO_2 (ml.kg$^{-0.75}$.m^{-1}) and HR (bpm) demonstrated excellent reliability (ICC > 0.90 and CV < 10%) across the two trials (Table 3). All RE variable measurements were within the TE associated with measuring treadmill running (1.5 - 5%) (Saunders et al. 2004) (Table 4). Both cycle and run BLa demonstrated lower between trial reliability than other physiological variables [cycle: ICC 0.76 (95% CI (0.53 - 0.90), CV 21.6%, and run: ICC 0.84 (95% CI 0.58 - 0.95), CV 19.2%] (Table 4). Table 4 highlights no significant differences between any variables measured across the two trials.

Participants mean power output (W) was precisely replicated during each of the two trials with the mean power demonstrating excellent reliability [ICC 0.99 (95% CI 0 .99 – 1), CV 0%]. Participants also demonstrated excellent reliability of RPE measurements

Table 2. Mean ± σ values for performance and physiological variables measured during 60-minute stationary cycle at 60 % of w$\dot{V}O_{2max}$ of simulated triathlon.

	Trial 1	Trial 2
Bike		
Economy (W·LO$_2$·kg^{-1})		
Sample 1	75.26 ± 4.22	74.16 ± 4.89
Sample 2	73.61 ± 2.95	74.1 ± 4.55
Sample 3	74.99 ± 4.68	71.95 ± 2.77
BLa (mmol·l^{-1})		
Sample 1	3.73 ± 1.67	3.4 ± 1.72
Sample 2	2.71 ± 1.13	2.3 ± 1.20
Sample 3	2.13 ± 1.15	1.84 ± 0.67
HR (bpm)		
HR1	144.3 ± 6.99	143.6 ± 8.69
HR2	139.8 ± 6.14	139.6 ± 5.78
HR3	140.9 ± 3.98	140.9 ± 4.43
W		
Sample 1	174.3 ± 42.13	174.5 ± 42.68
Sample 2	174.2 ± 43.36	174.5 ± 43.91
Sample 3	176.2 ± 45.16	176.5 ± 45.76
RPE		
Sample 1	3.7 ± 1.9	3.7 ± 2.0
Sample 2	3.8 ± 1.9	3.8 ± 1.9
Sample 3	3.9 ± 2.0	3.9 ± 2.1

BLa: blood lactate concentration, W: Watts, RPE: Rating of Perceived Exertion HR: heart rate, bpm: beats per minute, Sample 1: Taken during minutes 7 -12, Sample 2: Taken during minutes 27 – 32, Sample 3: Taken during minutes 52 - 57 during the swim, cycle, run and overall (ICC > 0.90, CV < 10%).

Table 3. Mean ± σ values for performance and physiological variables measured during a 20 min run at 70% v$\dot{V}O_{2max}$ of simulated triathlon.

	Trial 1	Trial 2
	Mean ± SD	**Mean ± SD**
Run Physiological Measures		
$\dot{V}O2$ (ml·km-1)		
Sample 1	14.54 ± 2.56	14.55 ± 2.59
Sample 2	14.6 ± 2.55	14.56 ± 2.73
$\dot{V}O2$ (ml·kg$^{-0.75}$·km^{-1})		
Sample 1	618.24 ± 15.57	617.39 ± 17.92
Sample 2	621.03 ± 15.83	616.85 ± 17.23
EC (kcal·km^{-1})		
Sample 1	60.22 ± 11.41	60.21 ± 11.41
Sample 2	60.36 ± 11.23	60.14 ± 11.75
EC·kg^{-1} (kcal·kg$^{-0.75}$·km^{-1})		
Sample 1	2.56 ± 0.31	2.56 ± 0.33
Sample 2	2.57 ± 0.31	2.55 ± 0.32
BLa (mmol·L^{-1})		
Sample 1	3.79 ± 1.69	3.71 ± 1.94
RPE		
Sample 1	4.6 ± 1.8	4.6 ± 1.8
Sample 2	4.7 ± 1.8	4.5 ± 1.6
HR		
Sample 1	160.3 ± 9.36	161.3 ± 8.47
Sample 2	163 ± 10.09	162.6 ± 9.60

BLa: Blood lactate concentration, RPE: Rating of Perceived Exertion HR: heart rate, VO_2:

Discussion

This study demonstrates that this newly developed simulated LD triathlon is highly task representative and has moderate to excellent levels of reliability when assessing physiological outcomes in LD specialist triathletes. This is the first study to examine the reliability of a LD triathlon and associated physiological measurements in both male and female LD specialists. All physiological measures commonly utilised in measuring reliability in sports sciences (Atkinson and Nevill 2001) displayed moderate to excellent levels of reliability (Koo and Li 2016).

As previously suggested a performance test should only be used if it is reliable and closely replicates the demands of the race or sporting event, therefore demonstrating high task representation (Hopkins 2000; Hopkins et al. 1999; Piggott et al. 2019). Due to the duration and logistics of LD triathlon (between 3.5 – 17 hours) and the substantial amount of muscular damage inflicted and inflammatory response from racing (Suzuki et al. 2006), it is not feasible to test improvements during a LD triathlon event or a simulated triathlon replicating these distances. The current study provides coaches and sport scientists with a high task representative test which may be implemented to accurately assess physiological changes in LD specialists in a research and practical training environment.

Literature displaying high reliability (ICC > 0.8, CV < 10%) of key physiological and performance variables during a simulated triathlon or RBR have only utilised SD triathletes over distances reflective of SD events (Taylor 2012; Vleck et al. 2012). Due to variations in training, race strategies and pacing between SD and LD triathletes, it is not feasible to assess LD triathlon specialists in a simulated SD triathlon to accurately measure physiological changes. The current study demonstrates similarly high levels of reliability in LD specialists over distances more suitable for LD triathlon events. The current study emphasised the importance of measuring key physiological variables (RE, VO_2, EC and cycling economy (CE)) as these have previously been identified as determinants of success in endurance performance (Saunders et al. 2004; Suriano and Bishop 2010).

Measurements of RE, VO_2 and EC in the current study had excellent reliability (ICC > 0.9, CV < 10%) and reflected ICC and CV values demonstrated in previous

Table 4. Reliability measures of physiological and performance measures between trials.

	% difference between trials (mean ± S.D)	ICC (95% CI)	Typical error (TE)	CV (%)	p-value
Physiological variable					
CE (W·LO_2·kg^{-1})	4.23 ± 0.03	.62 (.35 - .83)	2.83	3.8%	.11
Cycle BLa (mmol·L^{-1})	19.7 ± 18.5	.76 (.53 - .90)	0.58	21.6%	.30
Cycle HR (bpm)	2.2 ± 2.5	.65 (.40 - .84)	3.41	2.4%	.74
Energy Cost (kcal·km^{-1})	4.2 ± 3.5	.95 (.88 - .98)	1.73	2.9%	.81
EC/km (kcal·kg$^{-0.75}$·km^{-1})	3.2 ± 2.9	.98 (.95 - .99)	0.08	3.1%	.89
$\dot{V}O2$ (ml·km^{-1})	3.3 ± 2.8	.98 (.94 - .99)	0.40	2.7%	.75
$\dot{V}O2$ (ml·kg$^{-0.75}$·km^{-1})	2.52 ± 27.2	.93 (.82 - .96)	0.02	8.2%	.68
Run BLa (mmol·l^{-1})	14.9 ± 16.6	.84 (.58 - .95)	0.72	19.2%	.81
Run HR (bpm)	16.13 ± 1.2	.92 (.80 - .97)	2.35	1.4%	.69
Performance variable					
Swim time (s)	1.95 ± 1.8	.96 (.88 - .99)	31.28	1.9%	.62
Swim RPE	3.3 ± 7	.96 (.89 - .99)	0.30	0.1%	.17
T1	5.8 ± 7.2	.87 (.64 - .96)	23.10	5.9%	.93
Cycle (W)	0	.99 (.99 – 1)	0.67	0%	.13
Cycle RPE	0	.97 (.93 - .99)	0.32	0%	1
T2	2.9 ± 3.1	.98 (.96 - .99)	9.43	20.2%	.20
Run RPE	0	.98 (.96 - .99)	0.22	6.7%	.16
OA RPE	0		0	0	-

n = 10, σ = standard deviation, ICC = intraclass correlation, TE = typical error of measurement, CV = coefficient of variation, CE: cycling economy, BLa: Blood lactate concentration, HR: heart rate, bpm: beats per minute, RPE: Rating of Perceived Exertion, $\dot{V}O_2$: Oxygen uptake, EC: Energy cost, (s): seconds, (W): watts, T_1: first transition, T_2: second transition, OA: overall research examining SD triathletes in simulated reliability studies (Taylor 2012; Vleck et al. 2012). Research examining the reliability of physiological variables are frequently exposed to measurement errors associated with equipment, testing and biological variations resulting in a TE associated with testing (Hopkins 2000). In moderately trained athletes, intra-individual variations result in TE measurements between 1.5 – 5% depending on athlete ability (Saunders et al. 2004). This would indicate that RE measurements on a treadmill are relatively stable. In the current study, all RE variables were within the TE for measuring RE, further demonstrating high reliability of RE measurements in the current study compared to previous research. These findings will allow coaches or sport scientists to be confident that a real change has occurred in RE measurements after a pre fatiguing swim and cycle. Further, the current study also displayed RE expressed as EC, which has been postulated to be a more valid and reliable measure of RE as it accounts for different substrate utilization during running (Curran-Everett 2013). High task representative design is demonstrated in the current LD simulated triathlon by the selection of a velocity relative to each participant (70% of vVO_{2max}) used to measure RE. To optimise RE measurements, it is essential to select a speed relative to each participants VO_{2max} and ensure it is a speed they practice and race most at (Saunders et al. 2004). Typically, research examining RE measurements use durations between 3 – 15 minutes at a speed lower than the participants lactate threshold (LT) (Saunders et al. 2004). Additionally, previous literature examining the RE of elite and recreational marathon runners has demonstrated a 30 – 40% variation between athletes (Morgan and Daniels 1994), emphasising the importance of selecting a velocity relative to each athlete. A pace of 70% of vVO_{2max} was selected for the simulated triathlon implemented as part of this research to ensure all participants were tested at a velocity slower than their LT and at a pace which could be sustained over the duration of a half marathon (21.1km) or marathon (42.2km) whilst accommodating for the pre fatiguing swim and bike.

In the current study, BLa measurements taken during the run discipline demonstrated good ICC values (0.84), however the CV between tests was 19.2%. Literature examining the reliability of running physiological measures also identified BLa as the variable with the highest variation (CV 10 - 52%) (Saunders et al. 2004), demonstrating that BLa may not be as reliable as other variables when examining physiological improvements. Whilst it is acknowledged that LD triathletes run substantially longer than 20 minutes during racing, research examining RE variables in reliability studies use running assessment durations between 3 – 15 minutes to accurately measure changes in participants RE (Saunders et al. 2004). In endurance athletes, RE is considered a superior predictor of endurance performance than VO_{2max} and is considered an important factor in determining success in long distance runners (Saunders et al. 2004).

Cycling economy demonstrated moderate reliability (ICC 0.62, CV 3.8%) in the current study however this ICC value is slightly lower than results displayed in previous literature examining CE in a simulated triathlon or RBR (Taylor 2012; Vleck et al. 2012). The ICC result for CE may be due to a small sample size (n = 10) and the long duration of the cycle discipline of this study (60 minutes). With increases in exercise duration, a gradual drift in VO_2 is commonly observed, resulting in a reduction of athlete's economy of movement (Passfield and Doust 2000). At a given power output, changes in cadence may also decrease efficiency of cycling (Hopker et al. 2009). Previous research suggests controlling cadence for optimal measurements for cycling efficiency, however participants in this study were able to freely choose their cadence as they would during LD competition. The self-selected cadence may contribute to the lower ICC for CE demonstrated in this study. The swim distance in the current study (1500 m) was also longer than that in a SD simulated triathlon (750 m). This could have contributed to an increase in residual fatigue experienced during the subsequent cycle and, therefore further negatively impacting CE (Peeling and Landers 2009; Peeling et al. 2005). It should be noted that the CV of CE (3.8%) was similar to studies examining the efficiency of cycling, demonstrating high CV reliability (3.7 – 11.35%) (Moseley and Jeukendrup 2001).

Long and short distance specialist triathletes adopt different swimming paces and strategies, which may influence the outcomes of cycling and running performance, therefore impacting the overall result (Abbiss et al. 2006; Laursen 2011; O'Toole et al. 1989; Vleck et al. 2010; Wu et al. 2015). Participants in this study were asked to complete a 1500 m swim at 85% of their perceived maximum effort. The swim distance of 1500 m replicates that completed during an OD event. In shorter distance simulated tests, participants were instructed to swim at 80 – 95% of their 750 m maximal swim pace, however it is likely that LD triathletes may swim at a lower intensity to conserve energy for the subsequent long cycle and run disciplines (Peeling and Landers 2009). For this reason, the swim was to be completed at 85% of the participant's perceived maximal effort. Results from this study demonstrate that LD specialists may be able to accurately self-pace their perceived 'race pace' effort in a simulated triathlon and be able to reliably replicate this (ICC 0.96, CV 1.90%). Future studies utilising a LD simulated triathlon for LD specialist athletes may not need external pacing to enable the LD triathletes to complete a pre fatiguing swim at their perceived race pace.

In the current LD simulated triathlon, participants RPE was collected at the end of the swim, throughout the cycle and run disciplines and at the completion of the test. This is the first study to assess the reliability of RPE as a performance variable in a LD simulated triathlon. RPE is an affordable, practical and valid tool used for monitoring exercise intensity and is strongly correlated with HR and BLa (Scherr et al. 2013). In moderately trained triathletes completing a cycle-run, those who reported higher RPE values at the end of the cycle demonstrated significantly higher impairments in RE, demonstrating that RPE may be a cost-effective measure used by triathletes to optimise RE during racing (Bonacci et al. 2013). The current study supports the utilisation of RPE as a simple and reliable tool as RPE measurements in the current simulated triathlon displayed excellent reliability (ICC > 0.95, CV 0 – 6.7%).

Field tests have limited application in predicting LD triathlon performance (Marongui et al. 2013) however literature demonstrates that performance in an 'iron' distance race may be predicted from the athletes personal best OD time (Rust et al. 2011). For this reason, the simulated triathlon in this study replicated distances close to that of an OD triathlon. Additionally, the cycle discipline of LD triathlon events has the greatest influence on the overall outcome of LD racing. The simulated triathlon in the current study was designed to replicate race strategies and pacing implemented by LD triathletes, with an emphasis on a longer cycle (60 minutes). The adaption of different race strategies and pacing across SD and LD triathlon and variations in draft legal (SD) and non-draft legal (LD) bike legs, influences pacing and surges during the cycle section of a triathlon (Bentley et al. 2002; Vleck et al. 2010). To optimise performance over the duration of LD triathlon, it is recommended that LD specialist athletes generally attempt to perform an even pacing strategy during both the cycle and run (Abbiss and Laursen 2008; Laursen 2011; O'Toole et al. 1989). This even pacing strategy was adopted in the current study with both the cycle and run disciplines completed at a pre-set power or run pace. Furthermore, LD specialists may use a power meter with a race plan tailored to an individualised functional threshold power output for the cycle discipline, therefore their performance is not strongly determined by other athletes as it is in OD or SD triathlons. When measuring CE in athletes, the work rate utilised during testing should replicate that of the functional range used by the athletes of interest (Hopker et al. 2009). In elite triathletes, the mean power output observed in the cycle leg of an OD triathlete is approximately 61.4% and 63.4% of maximal aerobic power for women and men respectively (Le Meur et al. 2009). For this simulated triathlon, intensity of the cycle discipline was decreased to 60% of wVO_{2max} to accommodate for non-elite athletes and to ensure participants were below predicted LT for optimal economy measurements (Abbiss et al. 2006; Le Meur et al. 2009; Wu et al. 2015). Furthermore, this intensity was selected to avoid the VO_2 slow component associated with higher intensities of cycling which should not be used when measuring CE (Hopker et al. 2009).

During the simulated triathlon of the current study, the run and cycle disciplines were pre-set to a consistent power or pace based of each participants wVO_{2max} (60%) and vVO_{2max} (70%), replicating the demands of LD triathlon and allowing for a greater accuracy of physiological measurements (Abbiss et al. 2006; Le Meur et al. 2009; Wu et al. 2015). It is therefore not unexpected that the performance variables of RPE and power (Watts) held during the cycle discipline demonstrated excellent reliability.

Practical applications

For coaches and sport scientists to test and monitor athletes progress from training interventions with confidence, assessments utilized should be reliable and represent the competition demands and behaviours of athletes in training and/or competitions. A LD simulated triathlon that consists of a 1500 m swim at race intensity, a 60 minute cycle at 60% wVO_{2max} and a 20 minute run at 70% vVO_{2max} has a moderate to excellent level of reliability with all physiological measurements (except BLa and cycling HR) displaying excellent, good or moderate reliability between trials (ICC 0.64 - 0.99, CV < 10%). The current LD simulated triathlon directly replicates the demands of LD triathlon and demonstrates high task representation. Therefore, this simulated triathlon may be used to accurately assess physiological changes in LD triathletes in a research and training setting. This test may be a more appropriate assessment than previously established reliable simulated triathlon measures for LD triathletes (Taylor 2012; Vleck et al. 2012).

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