

ORIGINAL ARTICLE

Effect of swimming intensity on subsequent cycling and overall triathlon performance

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Objectives: To investigate the effects of different swimming intensities on subsequent cycling and overall triathlon performance.

Methods: Nine highly trained, male triathletes completed five separate laboratory sessions comprising one graded exercise test, a swim time trial (STT), and three sprint distance triathlons (TRI). The swimming velocities of the three TRI sessions were 80–85% (S80), 90–95% (S90), and 98–102% (S100) of the STT velocity. Subsequent cycling and running were performed at a perceived maximal intensity. Swimming stroke mechanics were measured during the swim. Plasma lactate concentration and ratings of perceived exertion were recorded at the conclusion of the swim and over the course of subsequent cycling and running. Oxygen consumption was recorded during the cycle.

Results: The S80 and S90 cycle times were faster than the S100 cycle time ($p < 0.05$). The overall triathlon time of S80 was faster than that of S100 ($p < 0.05$). The S100 swim was characterised by a greater stroke rate than S80 and S90 ($p < 0.05$) and a greater plasma lactate concentration than S80 ($p < 0.01$).

Conclusion: A swimming intensity below that of a time trial effort significantly improves subsequent cycling and overall triathlon performance.

The multidisciplinary sport of triathlon comprises three different modalities conducted in succession. It has been proposed that, throughout a triathlon, the residual effect of prior exercise creates physiological responses that differ from performing the three disciplines as individual events.¹ However, few triathlon investigations have considered the interaction between the three disciplines with a performance based objective.

Most triathlon research has focused on the effect of cycling on subsequent running performance. Previous research has shown that the pedalling cadence cycled at² or perseveration of prior cyclic motor activity³ can influence the stride patterns of subsequent running. Such findings may have implications for overall triathlon performance, but these studies have not considered the initial effect that the swimming discipline may have on these outcomes, thereby limiting their application.

To date, little research has focused on the swimming aspect of a triathlon, possibly because of suggestions that the swim completion time has little relation to overall race time.^{4–5} Furthermore, it has been suggested that a 3000 m swim had no significant effect on the power output of a subsequent three hour ride.⁶ In contrast, Kreider *et al*¹ reported a 17% decrease in cycling power output after an 800 m swim, relative to the power output achieved during an isolated cycling bout. The disparity between these studies may be due to the different swim distances and intensities (1.25 m/s *v* 1.05 m/s), possibly suggesting that a threshold swim intensity exists that is detrimental to subsequent cycle performance. However, to date, no investigation has explored such a proposal by specifically manipulating the swim intensity before a cycle.

The possible influence of the relative swim intensity has been highlighted through triathlon studies investigating the effects of drafting and wetsuits.^{7–9} These strategies allow a reduced relative swimming intensity for a given work output, supporting the idea that manipulation of the swim discipline may provide a reserve of metabolic energy directly available

in the succeeding triathlon disciplines, which could further influence overall race success.

The purpose of this study therefore was to examine the effects of swimming intensity on subsequent cycling and overall sprint distance triathlon performance. We focused on the sprint distance triathlon, as this event accounted for 50% of all professional races throughout Australia over the 2003/04 season. It was hypothesised that completing the swim leg at an intensity equivalent to that of a time trial effort would compromise the subsequent cycling and overall race performance.

METHODS

Subjects

Nine highly trained, male triathletes were recruited as subjects (table 1). All participants were briefed on the purpose, requirements, and risks of involvement. Written consent was signed in accordance with the requirements of the human ethics committee of the University of Western Australia.

Experimental overview

Each athlete attended five separate laboratory sessions comprising one graded exercise test (GXT), a swim time trial (STT), and three sprint distance triathlons (TRI). Throughout each TRI, the swim intensity was varied according to the individual's performance during the STT. Each test was separated by a minimum of 48 hours and was conducted at the same time of day. Subjects refrained from intensive exercise for 24 hours before testing. All swimming was conducted in a six lane, 25 m outdoor pool, heated to 28°C. The GXT and all cycling sessions were conducted on a wind braked cycle ergometer (Evolution Pty Ltd, Adelaide,

Abbreviations: GXT, graded exercise test; RPE, rating of perceived exertion; SSL, swim stroke length; SSR, swim stroke rate; STT, a swim time trial; S80, S90, and S100, 80–85%, 90–95%, and 98–102% of the velocity achieved for the STT; TRI, sprint distance triathlon; $\dot{V}O_{2PEAK}$, peak oxygen consumption

Table 1 Descriptive subject data

Variable	Mean	SD
Age (years)	21.2	2.6
Mass (kg)	77.5	3.8
Height (cm)	187.1	6.1
VO ₂ PEAK (ml/kg/min)	68.77	8.07
Lactate threshold (%VO ₂ PEAK)	76.08	7.18
Lactate threshold power (W)	307.97	42.26

VO₂PEAK, Peak oxygen consumption.

Australia) with six gear ratios through which subjects were free to change during all cycle sessions. Running was performed on a 250 m grass track.

GXT

The GXT was conducted to determine peak oxygen consumption (VO₂PEAK) and lactate threshold using four minute work and one minute rest periods. The initial workload was 100 W, with subsequent 40 W increments over each work period until volitional exhaustion. Expired air was analysed for concentrations of O₂ and CO₂ (Ametek Gas Analysers SOV S-3A/1 and COV CD-3A; Applied Electrochemistry, Pittsburgh, Pennsylvania, USA). Ventilation was recorded at 15 second intervals using a turbine ventilometer (225A; Morgan, Chatham Kent, UK). VO₂PEAK was determined by summing the four highest consecutive 15 second VO₂ values. Arterialised capillary blood samples (35 µl) were collected from the earlobe during the one minute rest periods. Blood was analysed for plasma lactate concentration using a blood gas analyser (ABL 625; Radiometer Medical A/S, Copenhagen, Denmark). The lactate threshold was determined using the modified D_{max} method.¹⁰

STT

A standardised 500 m warm up was completed immediately before the STT. The STT required subjects to swim 750 m in the shortest time possible. During the STT, 100 m lap split times were recorded. During the last 20 m of each 100 m split, the number of strokes and the time taken to swim the 20 m was recorded. This allowed determination of the subject's swim stroke rate (SSR: cycles/min) and swim stroke length (SSL: m/cycle).

Triathlon testing sessions

Before each TRI, subjects performed the STT warm up. The swim intensities used during S80, S90, and S100 were 80–85%, 90–95%, and 98–102% of the velocity achieved for the STT respectively. During the swim, a land based pacer provided auditory signals at each 100 m split to indicate that the athlete should be approaching a turn or beginning the next 100 m split. This method allowed consistent lap pacing.

After the swim, subjects immediately moved into the laboratory and on to the bike. They were required to cycle 500 kJ of work (~20 km¹¹) as quickly as possible at a freely chosen gear ratio and power output. Total work and mean power output were measured by a customised computer program (Cyclemax; School of Human Movement & Exercise Science, University of Western Australia). Expired air was collected during the work periods of 0–100 kJ, 200–300 kJ, and 400–500 kJ by methods mentioned above. Expired air and power output data were used to determine cycling gross efficiency, calculated by dividing mechanical work by energy cost.¹³ At the completion of the cycle, athletes progressed outside for the run.

Capillary blood was sampled before the swim warm up, after the swim, at five minute intervals during the cycle leg, and immediately after the run. At the completion of each

individual discipline, subjects reflected on an overall rating of perceived exertion (RPE) using the Borg perceptual scale.¹²

Statistical analysis

Results are expressed as mean (SD). Repeated measures analysis of variance were used to analyse the influence of swimming intensity on triathlon performance using swim time, RPE, blood lactate concentration, and VO₂ as dependent variables. Pairwise comparisons were made post hoc to identify specific between group differences. A Bonferroni correction was applied, and the α level was set at $p \leq 0.05$.

RESULTS

Individual discipline split times

The mean STT times for S80, S90, and S100 were 733.6 (65.7), 672.6 (57.3), and 619.2 (54.9) seconds respectively (fig 1). All three experimental swim times were significantly different from one another ($p < 0.01$). No differences were found between the STT and the S100 swim time ($p = 0.99$). The mean cycle times for S80, S90, and S100 were 1654.1 (140.3), 1682.3 (155.2), and 1808.7 (201.8) seconds respectively (fig 1). The S80 ($p = 0.003$) and S90 ($p = 0.012$) cycle times were faster than the S100 cycle time. There were no differences between S80 and S90 ($p = 0.999$). The mean run times for S80, S90, and S100 were 1208.7 (73.9), 1258.0 (78.3), and 1265.1 (75.2) seconds respectively (fig 1). No differences existed between these outcomes ($p = 0.070$).

Overall triathlon time

The mean overall triathlon times for S80, S90, and S100 were 3658.1 (164.8), 3681.0 (213.6), and 3763.4 (222.1) seconds respectively (fig 1). The S80 condition was faster than S100 ($p = 0.050$). No differences existed between S80 and S90 ($p = 0.999$) or S90 and S100 ($p = 0.091$).

Cycling power

The overall mean power outputs for S80, S90, and S100 were 304.6 (24.4), 297.6 (28.8), and 277.8 (30.8) W respectively. The mean S100 power output was lower than the S80 ($p = 0.003$) and S90 ($p = 0.003$) power outputs. The higher mean power output during S80 compared with S100 occurred at minutes 10, 15, and 20 (S80–S100 difference 41.4 (30.4) W ($p = 0.010$), 24.7 (19.5) W ($p = 0.016$), and 25.3 (16.5) W ($p = 0.024$) respectively; fig 2). The mean power output for S90 between 15 and 20 minutes was greater than for S100 (S90–S100 difference 20.6 (18.9) W).

Swim stroke mechanics

The SSRs for S80, S90, and S100 were 25.5 (1.5), 29.0 (2.2), and 32.1 (2.7) cycles/min respectively (fig 3A). The differences between S80 and S90 ($p = 0.001$), S80 and S100 ($p = 0.0001$), and S90 and S100 ($p = 0.015$) were significant. The SSLs recorded during S80 (2.2 (0.2) m/cycle), S90 (2.2 (0.2) m/cycle), and S100 (2.7 (0.2) m/cycle) were not different ($p > 0.05$) (fig 3B).

Physiological variables

No differences were found between the recordings of VO₂ ($p > 0.05$) (table 2). The cycling gross efficiency during the first 100 kJ was greater for S80 than for S100 ($p = 0.017$). At this same work period, no differences existed between S80 and S90 ($p = 0.999$), or S90 and S100 ($p = 0.61$).

At the completion of the swim there was a significant difference in blood lactate between S80 (5.2 (2.5) mmol/l) and S100 (9.1 (2.7) mmol/l) ($p = 0.002$), whereas there was no difference between S90 (6.7 (3.6) mmol/l) and S100 ($p = 0.078$). During the initial five minutes of cycling, the blood lactate for both S80 (8.1 (4.4) mmol/l) and S90 (9.1 (2.9) mmol/l) were lower than for S100 (11.3 (2.6) mmol/l)

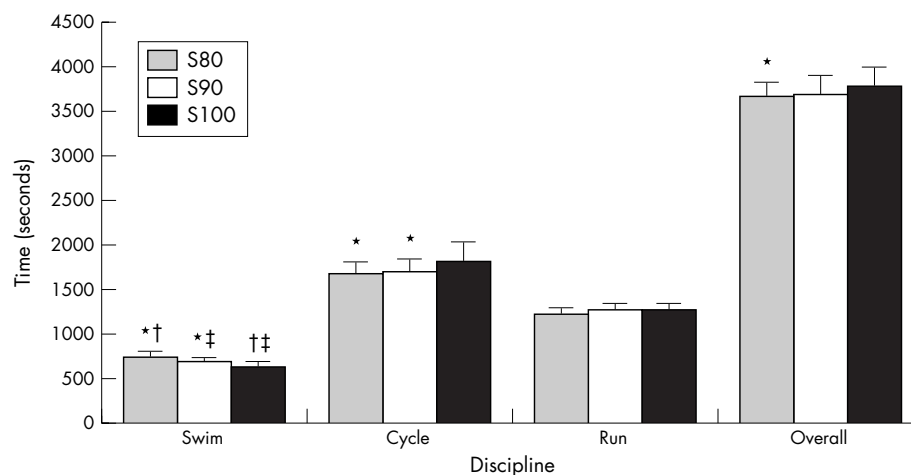


Figure 1 Individual discipline times and overall triathlon times for S80, S90, and S100. *Significantly different from S100 ($p \leq 0.05$). †Significantly different from S90 ($p \leq 0.05$). ‡Significantly different from S80 ($p \leq 0.05$). S80, S90, and S100, 80–85%, 90–95%, and 98–102% of the velocity achieved for the swim time trial.

($p = 0.033$ and $p = 0.017$ respectively). Throughout the remainder of the cycle leg and at the conclusion of the run, there were no differences in blood lactate between conditions ($p > 0.05$).

RPE

At the completion of the swim, the RPE for S80 (10 (2), $p = 0.002$) and S90 (11 (2), $p = 0.008$) were lower than for S100 (15 (2)). The RPE for S80 (14 (2)) was lower than for S90 (16 (1)) and S100 (16 (2)) at the completion of the cycle ($p = 0.007$ and $p = 0.003$ respectively). No differences in RPE existed at the completion of the run ($p > 0.05$).

DISCUSSION

The findings of this study suggest that swimming intensity had a significant influence on subsequent cycling and overall triathlon performance during a simulated, sprint distance triathlon. Specifically, compared with a STT (100%), swimming intensities 80–85% and 90–95% of a time trial velocity were associated with improved cycling and overall triathlon performances (S80 only).

The cycle times for S80 and S90 were significantly faster than for S100, suggesting that a time trial intensity swim impairs subsequent cycling performance. This supports the notion that the residual effects of prior exercise increase the

physiological demands of performing the subsequent disciplines of a triathlon.¹ Previous research shows that, after a bout of exhaustive high intensity cycling, subsequent bouts of high intensity exercise were not attainable for a significant period of time.¹⁴ These authors concluded that activities performed with an ill considered pacing strategy would require a reduction in work rate in order to continue subsequent exercise at a level below the fatigue threshold.¹⁴ The time trial nature of the S100 swim was reflective of an ill considered pacing strategy, imposing a reduction in subsequent cycling work rate.

The greater cycling performances for S80 and S90 over S100 are a result of the greater mean power output. This may relate to the reduced metabolic disturbance, indicated by the lower plasma lactate concentration at the completion of the lower intensity swim. The greater plasma lactate

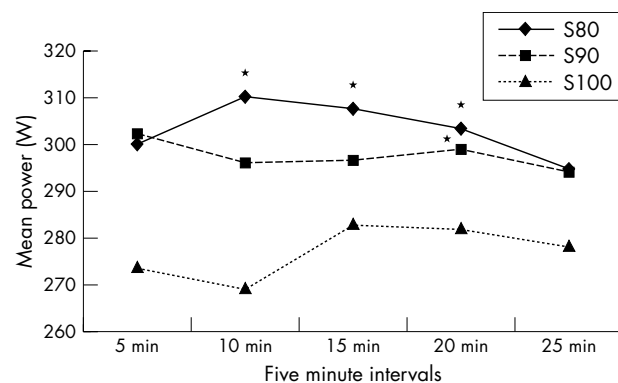


Figure 2 Mean power output at five minute intervals for S80, S90, and S100. *Significantly different from S100 ($p \leq 0.05$). S80, S90, and S100, 80–85%, 90–95%, and 98–102% of the velocity achieved for the swim time trial.

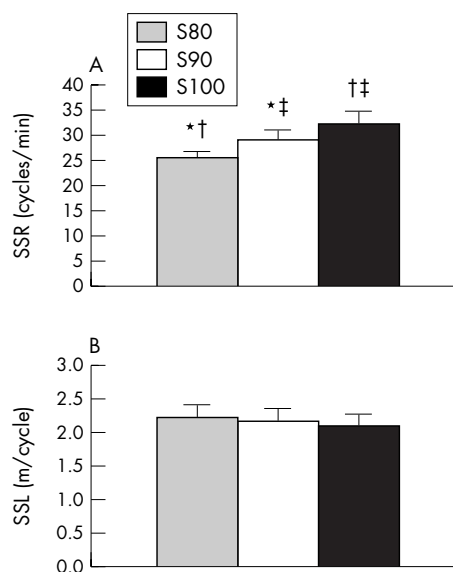


Figure 3 Swim stroke rate (SSR) (A) and swim stroke length (SSL) (B) recorded during the swim discipline for S80, S90, and S100. *Significantly different from S100 ($p \leq 0.05$). †Significantly different from S90 ($p \leq 0.05$). ‡Significantly different from S80 ($p \leq 0.05$). S80, S90, and S100, 80–85%, 90–95%, and 98–102% of the velocity achieved for the swim time trial.

Table 2 $\dot{V}O_2$ and gross efficiency (GE) data at specified work periods during cycling

	0–100 kJ				200–300 kJ				400–500 kJ			
	$\dot{V}O_2$		GE		$\dot{V}O_2$		GE		$\dot{V}O_2$		GE	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
S80	48.5	4.9	22.83*	1.08	49.73	2.3	22.58	1.7	50	3.43	21.9	1.79
S90	48.65	3.67	22.9	1.7	49.46	3.6	22.51	1.9	49.94	3.91	22.5	2.14
S100	48.07	3.68	20.7	1.19	47.09	3.3	22.06	1.2	47.49	2.63	21.71	1.46

*Significantly different from S100 ($p \leq 0.05$).

S80, S90, and S100, 80–85%, 90–95%, and 98–102% of the velocity achieved for the swim time trial.

concentrations for S100 possibly resulted from the greater SSR observed with an increased swim intensity. The increase in SSR may have induced a change in the proportions of muscle fibre types recruited throughout the S100 swim. This has been shown during cycling, suggesting that higher pedalling cadences required the additional recruitment of fast twitch muscle fibres, ultimately decreasing muscle efficiency and increasing energy expenditure.¹⁵ To maintain the greater rate of ATP production of fast twitch muscle fibres, a greater contribution of glycolysis is required.¹⁶ This metabolic change resulting from a greater SSR may have contributed to the greater increase in blood lactate as the swim intensity increased.

Furthermore, it has been reported that intense prior arm exercise that raises circulating lactate concentrations similar to that of the present study can impair subsequent leg exercise.¹⁷ It was proposed that the concentration gradient between the plasma and the muscle was such that release of lactate and possibly H^+ from the leg muscle was decreased, leading to a lowered muscle pH.¹⁷ Furthermore, a reduced H^+ diffusion capacity from the muscle occurs when the surrounding environment is acidotic,¹⁸ resulting in a greater accumulation of H^+ , which has been implicated as a cause of muscular fatigue.¹⁹ Therefore it is possible that the increased plasma lactate and probable H^+ accumulation occurring at the S100 intensity was associated with impaired H^+ efflux from the muscles used during cycling, thereby decreasing their pH and contraction capacity.

The five minute power output shows that the greater cycle performances for the S80 and S90 intensities were due to a greater work output during the initial cycling phases. This may be explained by the GE calculations, as the first 100 kJ of work during S80 was more efficient than during S100, allowing a greater work output for a given energy expenditure.²⁰ Furthermore, the mean differences in efficiency between S90 and S100 were similar to that of S80 and S100. However, this difference was masked by a large amount of subject variation. Ultimately, the lower swim intensities allowed the athletes to increase the efficiency of cycling during the initial work phases, thereby enhancing overall triathlon performance.

Complementary to the physiological changes, it is evident from the RPE that a lower intensity swim allowed subjects to perceive their physical status as more comfortable during the

swim-cycle combination. A relation exists between thoughts, perception of exertion, and athletic performance.²¹ Therefore it is possible that the lower swim intensity allowed more positive thoughts about the ability to perform throughout the remainder of the race.

Despite a non-statistical difference in run time, a tendency existed for the S80 run to be faster than the S90 and S100 runs (~1%). This small but potentially critical time improvement may have resulted from a greater conservation of energy during the swim, allowing a higher and more prolonged work output during the subsequent cycling and running disciplines. Performance enhancements of 0.8% are suggested to represent worthwhile improvements for elite level triathletes.²²

The overall S80 triathlon time was significantly faster than the S100 time, with a mean time improvement of ~1 min 45 s. Such improvements are particularly pertinent to coaches and elite athletes as the difference between first and second place at the 2004 world triathlon championships was only one second. In this context, it is worth noting that the mean time difference between S90 and S100 was ~1 min 22 s ($p = 0.091$), and that this difference appeared to fail to reach significance as a result of the large subject variance. These results suggest that elite male triathletes should consider swimming the first discipline of a sprint distance triathlon at an intensity below that of a time trial effort. However, in elite male triathlon races it is impossible to prevent athletes from drafting during the swim. Furthermore, it may be of importance for the athlete to exit the water in the first pack of swimmers to avoid missing the lead pack of cyclists that forms during a draft-legal triathlon. Therefore it may be more appropriate to recommend that triathletes improve their swimming ability through training, so that they are able to swim in the first pack of swimmers without encroaching upon an intensity threshold that exceeds 80–90% of their maximal intensity. Hence, the importance of a well structured swimming programme for elite male triathletes is highlighted.

CONCLUSION

This study shows that the swimming intensity during a sprint distance triathlon does affect the subsequent cycle and overall triathlon performance. Specifically, completing the swim leg at

What is already known on this topic

- The summated effect of performing successive exercise modalities creates physiological responses that differ from performing the disciplines as individual events
- Swimming has been shown to decrease subsequent cycling power output when compared with isolated bouts of cycling

What this study adds

- This study shows the physiological and performance based outcomes that occur during subsequent cycling and running as a result of changing the intensity at which the swimming discipline is performed
- A racing strategy encompassing a swimming intensity below that of a time trial velocity is more conducive to subsequent cycling and overall triathlon performance

a maximum time trial intensity is not conducive to the ensuing discipline performances. It is recommended that elite male triathletes consider a training programme with an importance placed on swimming equal to that of both cycling and running, so that the athlete is able to swim the initial discipline of an event at an intensity below maximum, without losing touch with the first pack of swimmers.

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COMMENTARY

The authors provide timely information about the effects of prior swimming intensities on cycling and overall triathlon performance. They show that swimming intensities of 80–85% and 90–95% of a time trial velocity improve cycling and triathlon performance, whereas a time trial intensity swim impairs subsequent cycling and overall race performance. Such observations are in agreement with the earlier report by Kreider *et al*¹ and, in principle, with the report by Boone and Kreider² of a residual effect of prior exercise that decreases performance. The latter report showed that 10 minutes of prior bicycle exercise led to a decrease in treadmill efficiency. Whether the impaired performance is due to decreased muscle pH and contraction capacity, increased recruitment of fast twitch muscle fibres, and higher blood lactate concentrations, or positive thoughts at lower intensity swims remains unanswered. What is clear is that lower swim intensities enhanced overall triathlon performance. As time is critical to winning a triathlon race, the recommendation that swimming ability should be improved makes sense (along with a better race strategy). However, what is less clear is the reason for the lower mean power output at S100 than at S80 at the same oxygen consumption. Given that the time trial intensity swim impairs subsequent cycling, one might expect a significant difference between the VO_2 recordings during cycling. This was not the case. Also, although it is sometimes difficult and costly to determine cardiac output, it seems to be essential if the researchers are to understand the cardiovascular reasons for the findings reported.

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