Cycling Attributes That Enhance Running Performance After the Cycle Section in Triathlon

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**Purpose:** To determine how cycling with a variable (triathlon-specific) power distribution affects subsequent running performance and quantify relationships between an individual cycling power profile and running ability after cycling. **Methods:** Twelve well-trained male triathletes (VO_{peak} 4.9 ± 0.5 L/min; mass 73.5 ± 7.7 kg; mean ± SD) undertook a cycle VO_{peak} and maximal aerobic power (MAP) test and a power profile involving 6 maximal efforts (6 s to 10 min). Each subject then performed 2 experimental 1-h cycle trials, both at a mean power of 65% MAP, at either variable power (VAR) ranging from 40% to 140% MAP or constant power (CON) followed by an outdoor 9.3-km time-trial run. Subjects also completed a control 9.3-km run with no preceding exercise. **Results:** The 9.3-km run time was 42 ± 37 s slower (mean ± 90% confidence limits [CL]) after VAR (35:32 ± 3:18 min:s, mean ± SD) compared with CON cycling (34:50 ± 2:49 min:s). This decrement after VAR appeared primarily in the first half of the run (35 ± 20 s; mean ± 90% CL). Higher blood lactate and rating of perceived exertion after 1 h VAR cycling were moderately correlated \((r = .51–.55; ± ~.40)\) with a larger decrement in run performance. There were no clear associations between the power-profile test and decrement in run time after VAR compared with CON. **Conclusions:** A highly variable power distribution in cycling is likely to impair 10-km triathlon run performance. Training to lower physiological and perceptual responses during cycling should limit the negative effects on triathlon running.

**Keywords:** cycle run, power profile, constant power

In triathlon, the physical demands of each race depend on the host venue and race dynamics (positioning and tactics). Training specificity and development of effective tactical strategies for competition are perennial challenges for coaches and triathletes. The cycle section (before the run and after the swim section) of an Olympic-distance triathlon race at the elite level is ~1 hour long, and well-developed fitness and technical skills are especially important on criterium-type courses. Cycling is typically performed at a mean intensity of ~60% to 65% of an individual’s maximal aerobic power (MAP) with a highly variable power distribution including efforts of >130% MAP and sustained efforts at ~80% to 90% MAP. As cycle courses become more technical, individual and team tactics continue to evolve. The power variations encountered in the cycling section are larger and more frequent (N. Etxebarria, unpublished data, 2007–2008), presumably increasing the degree of physiological strain even for the stronger cyclists. The third and final section, the run (influenced by fatigue accumulated during the preceding cycling), is often decisive in determining the overall outcome of races, particularly for male competitors. Therefore, determining the consequences of race-specific cycling on subsequent 10-km running performance is important to characterize sport-specific race demands. This information would be useful to optimize sport-specific training, as well as physical and tactical capacities for enhancing triathlon performance.

The highly variable power distribution during the triathlon cycle section is likely to amplify differences in physiological response and performance outcomes associated with constant- versus variable-power cycling. Several experimental studies investigating the effects of variable power have employed relatively narrow power-variation fluctuations using repetitive intervals of the same duration and intensity. Some studies report that variable-intensity cycling (for durations of 30–60 min) favors subsequent running, while others report the opposite. These conflicting findings need to be resolved to clarify ambiguity on the effect of variable-power cycling on subsequent exercise by using sport-specific power variations and performance measures.

Drafting, variability in technicality of courses, and race tactics in Olympic-distance triathlon make it difficult to assess laboratory-based physiological and performance measurements that relate directly with race outcomes. Critical power, a traditional performance measure derived via ergometry testing, identifies the highest power that
can be sustained for an extended time (typically 30–60 min) without fatigue\textsuperscript{10} and correlates highly with performance in some endurance events such as cycling time trials.\textsuperscript{11} Given the inherent variability in power output within and between triathlon races, the athlete with the highest sustainable power output for 1 hour is not necessarily the most successful. A laboratory-based cycle test that assesses a triathlete’s ability to perform over a wide range of physiological domains is more relevant for performance evaluation and prediction. The “power profile” test has been used successfully in road cycling,\textsuperscript{12} and it is somewhat surprising that the performance capabilities of triathletes have not been similarly characterized.

The main aim of this study was to compare the effects of 1 hour cycling at 65% MAP incorporating a triathlon-specific power distribution with 1 hour constant-power cycling on subsequent running performance. A secondary aim was to study the relationships between maximal power produced during intermittent maximal cycling sprints of different durations and running performance after variable-power cycling.

**Methods**

**Experimental Design**

A controlled laboratory-based investigation was conducted to study how 1 hour of variable- (VAR) and constant-power (CON) cycling affect subsequent 9.3-km running performance compared with running with no preceding exercise. We also correlated running performance after CON and VAR with the ability to generate maximal power during short and longer efforts through a cycling power-profile test.

**Subjects**

Twelve well-trained male triathletes participated in this study. Their physical characteristics were age 28 ± 5 years, height 1.80 ± 0.06 m, body mass 73.4 ± 7.8 kg, VO\textsubscript{2peak} 4.9 ± 0.5 L/min (mean ± SD). The typical weekly training volume for the group was 4 hours of swimming, 8 hours of cycling, and 3 hours of running, with 1 higher-intensity running interval and 1 cycling interval session a week. Subjects were instructed to abstain from any physical exercise, caffeine, or alcohol and replicate the same dietary practice in the 24 hours before each trial. The study was approved by the Loughborough University Ethics Advisory Committee and the Committee for Ethics in Human Research at the University of Canberra. All subjects provided written informed consent after a verbal explanation of the study protocol and experimental procedures was provided to them.

**Preliminary Testing**

**MAP and Peak Oxygen Uptake.** After a 10-minute warm-up at 125 W, subjects performed a progressive incremental maximal test on an electromagnetically braked cycle ergometer (Excalibur Sport, Netherlands) to establish their peak oxygen uptake (VO\textsubscript{2peak}) and MAP. The starting power output was 150 W, and increments of 5 W every 15 seconds were employed to ensure that exhaustion was reached after ~10 minutes. Pedal cadence was freely chosen by each participant and kept constant during the test. The MAP was defined as the average of the 4 highest consecutive power outputs during the test. Expired ventilation was measured continuously throughout the test.

**Power Profile.** The power-profile test protocol, based on that described by Quod et al.,\textsuperscript{12} consisted of 6 maximal efforts (6, 15, and 30 s and 1, 4, and 10 min) with an active recovery period (~75–125 W) between efforts (174, 225, 330, 480, and 600 s). After a 10-minute warm-up (~125 W), the power-profile test was completed on a custom-built wind-braked cycle ergometer (Australian Institute of Sport, Canberra, Australia) fitted with the triathlete’s own pedals and adjusted to his usual bike position. Power was recorded at a frequency of 0.5 Hz. Each athlete self-selected cadence and was able to change gears during the efforts as required. Data were analyzed using SRM software (v 6.40.05, Schoberer Rad Messtechnik, Germany). The maximal efforts during the power-profile test were subsequently compared with maximal efforts of the same duration encountered during 12 race power profiles by 5 different athletes (over 7 different triathlon courses) during the international season of Olympic-distance triathlon during 2011 (unpublished data).

**Experimental Trials.** The experimental trials were performed at least 5 days after the preliminary testing. Each triathlete performed 3 different experimental trials: two 1-hour cycle trials at a 65% MAP mean power output, either CON or VAR, both followed by a 9.3-km run time trial. A third experimental trial consisted of a run time trial with no preceding cycling performed (NO-EX). The power distribution throughout VAR was characterized by variable intensities often encountered during races (40–140% MAP) and efforts of different duration (in order, 10, 40, 90, 30, and 20 s)—a representative section of a VAR trial is shown in Figure 1. All 3 trials were conducted in a counterbalanced and randomized order, at least 7 days apart. The cycling was performed in the laboratory using an electromagnetically braked cycle ergometer. For the CON and VAR trials, subjects performed a 10-minute warm-up at 125 W on the cycle ergometer, while the warm-up for the NO-EX run was a 20-minute low-intensity run. Subjects self-selected their preferred cadence during the first trial and were asked to replicate this cadence for the second trial to avoid any confounding effects on physiological or neuromuscular responses. Athletes were allowed to drink water ad libitum, but no sports drinks or other types of ergogenic aids were permitted. Immediately after both CON and VAR cycle trials subjects changed into their running shoes (taking ~90 s) and started their 9.3-km time-trial run. The start and finish line was
positioned outside the exit door of our ground-floor laboratory where the cycle ergometry was conducted. The run involved a 4-lap outdoor road course, and split times for each lap were recorded. At the end of the run subjects were asked to rate their effort on a scale of 0% to 100%: 0% representing no effort at all and 100% giving absolutely everything. Subjects also used a visual analog scale of 1 to 5 to indicate how they felt physically, with 1 representing terrible and 5 fantastic (Australian Institute of Sport, Effort-Sensation Scale, v2.10, January 2010).

**Anthropometric and Physiological Measurements.** Height, body mass, and sum of 7 skin folds (triceps, subscapular, biceps, supraspinale, abdominal, front thigh, and medial calf) were measured on the first visit to the laboratory. Pulmonary gas exchange was measured and analyzed by a custom-built open-circuit indirect calorimetry system described previously. The sampling rate was set to 30 seconds, and the mean of the 2 highest consecutive readings was used to determine an individual’s VO2peak during the maximal progressive test. Heart rate was recorded using a Polar heart-rate-monitoring system (Polar heart-rate monitor, Kempele, Finland) throughout the maximal test, at the end of each effort of the power profile, and at 20, 40, and 60 minutes of VAR and CON cycling. A 5-µL capillary blood sample was drawn from a fingertip at the termination of the maximal cycling test; after the 1-, 4-, and 10-minute efforts during the power profile; and after 60 minutes of both cycling trials to measure blood lactate concentration (BLa; Lactate Pro, Arkray, Kyoto, Japan). Hydration status was determined using a digital urine refractometer (UG-α, Atago, Japan) before each experimental trial. Rating of perceived exertion (RPE) with a scale of 0 (no exertion) to 10 (maximal exertion) was recorded at 20, 40, and 60 minutes during the cycling trials and at the end of each 9.3-km-run trial.

**Statistical Analysis.** Descriptive data are shown as mean ± SD. An analytical approach determining practical or clinical significance of effects using magnitude-based inferences and precision of estimation was employed. Mean effects of the CON and VAR power profiles on running performance were estimated via the unequal-variances t statistic. Precision of estimation was indicated with 90% confidence limits (CL). The difference between the 2 groups at any given point in time was expressed as a percentage of baseline score via analysis of log-transformed values, to reduce bias arising from nonuniformity of error. Standardized difference scores or the effect size (ES) between the groups was interpreted according to the following criteria: <0.2 trivial, 0.2 to 0.6 small, 0.6 to 1.2 moderate, 1.2 to 2.0 large, and >2.0 very large. A standardized effect was inferred to be unclear when its confidence interval spanned both substantially positive (+0.2) and substantially negative (–0.2) values. Pearson correlation analysis was used to measure the degree of association between different physiological and performance markers using a scale of magnitudes: <.1 trivial, .1 to .3 small, .3 to .5 moderate, and .5 to .7 large and extended to include .7 to .9 very large and >.9 nearly perfect. A correlation was deemed unclear if the confidence interval spanned both −.1 and +.1 values. To compare the magnitude of variation in pacing of the 9.3-km run for the 3 experimental groups, we computed a ratio of the percentage coefficients of variation (%CV) in quartile split times. Ratios within a range of 0.9 to 1.1 were considered trivial (see justification at http://yahoogroups.com/groups/sportscience/message/2538). Ratios <0.9 indicate that the pacing of split times was substantially less variable for the first measure of the comparison. Statistical significance was set at P < .05.
Results

Cycling MAP was 411 ± 39 W (mean ± SD), VO\textsubscript{peak} \(4.9 ± 0.5\) L/min, and sum of skin folds \(56 ± 15\) mm at baseline. All trials were performed with subjects in a euhydrated state (urine specific gravity <1.020). The 1-hour cycle trials at CON and VAR were performed at 65% MAP, equivalent to a mean power output of 267 ± 25 W for both trials.

Time-Trial Run Performance

Both runs with preceding cycling were substantially slower (Table 1) than the run with no cycling (33:42 ± 2:32 min:s). The overall 9.3-km-run time was 42 ± 37 s (mean ± 90% CL) slower after VAR (35:32 ± 3:18 min:s, mean ± SD) than after CON (34:50 ± 2:49 min:s). The decrement after VAR appeared primarily in the first half of the run (35 ± 20 s, mean ± 90% CL slower than CON). The variation in pacing of the 4-lap run was substantially greater after VAR than after CON (ratio of coefficient of variation = 0.79). The NO-EX run had the most evenly paced strategy, followed by the post-CON run (Figure 2).

The control run (NO-EX) elicited the highest response in BLa of the 3 running time trials (7.5 ± 2.4 mmol/L), with a trivial difference between trials (CON 5.9 ± 2.5 and VAR 6.7 ± 2.3 mmol/L, Table 1). Subjects reported they gave 94% ± 5% effort during the run after CON, 95% ± 6% during the run after VAR, and 93% ± 9% after NO-EX. There were trivial differences between the cycle strategies in how subjects felt during the run (3.1 ± 1 for CON and 3.1 ± 1 for VAR; scale 1–5), with an unclear difference between the 2 cycle strategies and NO-EX (3.4 ± 0.8).

One-Hour Constant- and Variable-Power Cycling

There was a very large difference in BLa at the end of 1 hour of cycling (Table 1), with a higher concentration after VAR (8.2 ± 3.6 mmol/L) than CON (3.3 ± 1.5 mmol/L). The RPE for CON and VAR was similar at 20 minutes (6.0 ± 1.6 vs 5.9 ± 1.3, respectively) but substantially higher for VAR at 40 minutes (6.9 ± 1.4 vs 6.3 ± 1.6 units) and 60 minutes (7.8 ± 1.1 vs 6.3 ± 1.6 units) of the 1 hour of cycling. Heart rate followed a similar pattern as RPE with a trivial difference between the cycling trials at 20 minutes (155 ± 13 vs 155 ± 16 for CON and VAR) but substantially higher at 40 minutes (162 ± 15 vs 156 ± 13 beats/min) and 60 minutes (161 ± 16 vs 155 ± 13 beats/min) in VAR. A better run time was associated with a lower BLa and RPE at the end of the 1-hour cycling trials (Figure 3).

Power-Profile Test

The RPE, VO\textsubscript{2}, and BLa during the power-profile test are shown in Table 2. The athletes performed their 4-

| Table 1 Percentage Difference and Magnitude-Based Inferences Between Blood Lactate Concentration (BLa) at 60 min and Rating of Perceived Exertion (RPE) and Heart Rate at 20, 40, and 60 min of the Cycle Trial After CON and VAR, all Three 9.3-km Experimental Run Times, and BLa at the End of the Three 9.3-km Runs |
|---------------------------------|-----------------|-----------------|-----------------|
| % difference ± 90%CL | P | Standardized difference ± 90%CL, qualitative inf. |
| Cycle BLa, 60 min | VAR–CON | 147 ± 26 | .00 | 2.01 ± 0.51, very large |
| Cycle RPE | | | | |
| 20 min | VAR–CON | –0.6 ± 13.9 | .93 | –0.02 ± 0.46, unclear |
| 40 min | VAR–CON | 10.2 ± 8.9 | .06 | 0.36 ± 0.32, small |
| 60 min | VAR–CON | 25.1 ± 11.6 | .00 | 0.79 ± 0.39, moderate |
| Cycle heart rate | | | | |
| 20 min | VAR–CON | 0.1 ± 3.1 | .97 | 0.01 ± 0.34, unclear |
| 40 min | VAR–CON | 3.5 ± 1.9 | .00 | 0.37 ± 0.20, small |
| 60 min | VAR–CON | 3.7 ± 2.1 | .00 | 0.40 ± 0.23, small |
| 9.3-km-run time | VAR–CON | 1.9 ± 1.7 | .07 | 0.21 ± 0.19, small |
| CON–NO-EX | 3.3 ± 0.7 | .00 | 0.40 ± 0.09, small |
| VAR–NO-EX | 5.3 ± 1.7 | .00 | 0.63 ± 0.21, moderate |
| BLa at end of run | VAR–CON | 11 ± 25 | .40 | 0.31 ± 0.64, unclear |
| NO-EX–CON | 21 ± 28 | .19 | 0.56 ± 0.72, small |
| NO-EX–VAR | 11 ± 18 | .28 | 0.32 ± 0.51, small |

Abbreviations: CL, confidence limits; inf., inference; VAR, variable-power cycling; CON, constant-power cycling; NO-EX, no prior exercise.
and 10-minute efforts at 90% and 88%, respectively, of their VO_{2peak}. The curvilinear relationship between power output and time generated by the cycling power profile in our triathletes was similar to that previously documented in road cyclists, although the power outputs were lower (offset) in comparison. This profile of the triathletes also compared well with the equivalent (time) maximal efforts encountered during the 12 cycling race profiles of elite-level triathlon races (Figure 4). However, our triathletes achieved higher power output in the short efforts but were not able to sustain as high a power output for the longer efforts as elite athletes did in racing.

One subject’s power-profile results were excluded due to early fatigue and subsequent inability to generate maximal power. The only clear predictor of impaired running performance after VAR cycling was the BLa response during the 10-minute effort of the power profile. Subjects with a higher BLa response had a bigger impairment of running performance after VAR (\( r = .50; -.04 \) to \( .81; 90\% \) confidence interval). Body mass was positively correlated with absolute mean power output during the 15-second (\( r = .82, .52-.94 \)) and 30-second (\( r = .83, -.66 \) to \( .35 \)) efforts. Absolute peak power output during the 6- and 15-second efforts was inversely correlated with running ability after both 1-hour cycling trials (\( r = .50-.67; -.40 \)). However, we were unable to identify clear relationships between peak and mean power output during the power-profile test and difference in run time between CON and VAR: peak power during 6-second (\( r = -.29, -.71 \) to \( .27 \)) and 15-second sprint (\( r = -.22, -.66 \) to \( .35 \)) and mean power during 1-minute (\( r = -.32, -.71 \) to \( .21 \)), 4-minute (\( r = .14, -.41 \) to \( .62 \)), and 10-minute (\( r = .16, -.40 \) to \( .63 \)) efforts.
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Discussion

The VAR cycle protocol implemented in this study during a 1-hour cycle trial characterized by a triathlon-specific power distribution substantially slowed the subsequent 9.3-km-run time. Nearly 85% of the time lost occurred during the first half of the run. The slower run time after VAR observed in the current study is in agreement with previous results over a 30-minute cycle and 5-km run. The elevated physiological responses during VAR cycling were most prominent toward the end of the cycle, just before the start of the run, which likely explains the slow start in the subsequent run section. Higher physiological and perceptual responses during VAR were substantially correlated with impaired running performance compared with CON. Power output during the power-profile test alone does not explain greater impairment in run performance after VAR.

The probable reason that the first running split was slowest after VAR is the elevated physiological (heart rate and BLa) state at the end of VAR cycling. The higher BLa concentration toward the end of VAR is accompanied by higher metabolic acidosis when buffering capacity is limited. This scenario could explain the higher associated RPE readings, compromising the start of the running performance after VAR. Such elevations in heart rate and BLa during VAR have not always been identified by studies implementing narrow power variations. The divergent findings between previous studies and our study reiterate the importance of implementing race-specific power fluctuations to better understand the physiological demands of the cycle section in triathlon and their impact on performance.

The current study involved a self-paced 9.3-km-run time-trial performance, which is slightly different from a pack-run scenario often seen at the start of the run of a triathlon race. Our data indicate that 1 hour of VAR leads to uneven pacing on subsequent running over a 4-lap run course. The athletes in this study were not worried about “race position,” yet the first half of the run was substantially slower after VAR than CON. The longer the sporting event (>10 min), the more beneficial it is to keep an even pace during racing. Despite this fact, the first split of a usual 4-lap-run course in triathlon, however, is often the fastest by as much as 1 km/h compared with the mean run speed for the rest of the run. In a race situation where tactics often dictate pacing, adopting a much faster first quarter of the run after a taxing variable-cycling section is likely to increase the risk of fatigue toward the finish line.

Assessing the power profile in our well-trained triathletes has allowed us to explore some of the key physiological determinants of performance in triathlon. A low BLa concentration after the 10-minute sustained bout correlated moderately with enhanced performance after VAR cycling. Lower BLa after a sustained maximal effort suggests enhanced lactate uptake within the muscle associated with a higher aerobic capacity. The positive relationship between a low BLa during the maximal 10-minute effort with a favorable running performance after VAR reinforces the benefits of a higher aerobic capacity to recover between high-intensity bouts. The power outputs of our well-trained subjects were

![Figure 4](image_url) — Mean power output during the 6-s, 15-s, 30-s, 1-min, 4-min, and 10-min maximal efforts (with proportionally increasing rest periods) during the power-profile test of the current study. The 12 race power profiles are taken from 7 different international courses involving 5 athletes and are equivalent to the maximal 5 s, 30 s, 1 min, and 10 min. The 15-s and 4-min values are the data points that best fit the curve (second-order polynomial-quadratic). Data from Quod et al (2010) indicate laboratory-based results for different maximal efforts from 12 well-trained cyclists. Error bars represent the 90% confidence limits.
consistently ~10% lower than those of road cyclists in a previous study across the efforts. We acknowledge the fact that athletes undertake a higher number of efforts during racing; however, our laboratory results in triathletes are in agreement with the laboratory results seen in cyclists, with a nearly perfect correlation (r = 1.00, 0.97–1.00) with the efforts displayed in the field. The higher absolute power output during the short cycling efforts was positively associated with a higher body mass and negatively correlated with run performance after 1 hour of cycling. Triathletes need to develop the capacity to generate adequate power in cycling by increasing relative power output (W/kg) without compromising subsequent running performance.

**Practical Implications**

In addition to impaired overall performance, a slower first half of the run section after VAR cycling could impair the ability to establish or sustain a favorable race position. Triathletes should avoid varying their pace too much during the run, aiming for a solid start to avoid a decay in speed in the latter stages. Triathletes with superior technical and physical cycling ability can save energy during the cycle section for the run by riding more conservatively, which might compromise race performance or, depending on tactical considerations, push to the lead, making weaker cyclists tired for the subsequent run. To lead, triathletes should develop their ability to adapt to the specific demands of power variability during 1 hour of cycling. Specific sustained interval training to overcome the high physiological and perceptual disturbances during triathlon cycling should minimize fatigue during the cycle and limit time lost on the subsequent run.

**Conclusion**

A 1-hour triathlon-specific variable-power cycling bout has a larger detrimental effect on subsequent running performance than cycling at a constant power output with no variation in intensity. Training to lower physiological and perceptual responses during cycling should limit the negative effects on subsequent run performance in triathlon.

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**References**

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