

Effect of cycling cadence on subsequent 3 km running performance in well trained triathletes

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Br J Sports Med 2003;37:154–159

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Accepted 13 June 2002

Objectives: To investigate the effect of three cycling cadences on a subsequent 3000 m track running performance in well trained triathletes.

Methods: Nine triathletes completed a maximal cycling test, three cycle-run succession sessions (20 minutes of cycling + a 3000 m run) in random order, and one isolated run (3000 m). During the cycling bout of the cycle-run sessions, subjects had to maintain for 20 minutes one of the three cycling cadences corresponding to 60, 80, and 100 rpm. The metabolic intensity during these cycling bouts corresponded approximately to the cycling competition intensity of our subjects during a sprint triathlon ($> 80\% \dot{V}_{O_2MAX}$).

Results: A significant effect of the prior cycling exercise was found on middle distance running performance without any cadence effect (625.7 (40.1), 630.0 (44.8), 637.7 (57.9), and 583.0 (28.3) seconds for the 60 rpm run, 80 rpm run, 100 rpm run, and isolated run respectively). However, during the first 500 m of the run, stride rate and running velocity were significantly higher after cycling at 80 or 100 rpm than at 60 rpm ($p < 0.05$). Furthermore, the choice of 60 rpm was associated with a higher fraction of \dot{V}_{O_2MAX} sustained during running compared with the other conditions ($p < 0.05$).

Conclusions: The results confirm the alteration in running performance completed after the cycling event compared with the isolated run. However, no significant effect of the cadence was observed within the range usually used by triathletes.

During the last decade, numerous studies have investigated the effects of the cycle-run transition on subsequent running adaptation in triathletes.¹ Compared with an isolated run, the first few minutes of triathlon running have been reported to induce an increase in oxygen uptake (\dot{V}_{O_2}) and heart rate (HR),²⁻⁴ an alteration in ventilatory efficiency (\dot{V}_E),⁵ and haemodynamic modifications—that is, changes in muscle blood flow.⁴ Moreover, changes in running pattern have been observed after cycling, such as an increase in stride rate^{3,6} and modifications in trunk gradient, knee angle in the non-support phase, and knee extension during the stance phase.³ These changes are generally related to the appearance of leg muscle fatigue characterised by perturbation of electromyographic activity of different muscle groups.⁷

Recently, from a laboratory study, Vercruyssen *et al*⁸ reported that it is possible for triathletes to improve the adaptation from cycling to running at an intensity corresponding to Olympic distance competition pace (80–85% maximal oxygen uptake ($< \dot{V}_{O_2MAX}$)). They showed a lower metabolic load during a running session after the adoption of the energetically optimal cadence (73 rpm) calculated from the \dot{V}_{O_2} -cadence relation⁸⁻¹¹ compared with the freely chosen cadence (81 rpm) or the theoretical mechanical optimal cadence (90 rpm).¹²

Furthermore, Lepers *et al*¹³ indicated that, after cycling, neuromuscular factors may be affected by exercise duration or choice of pedalling cadence. They observed, on the one hand, the appearance of neuromuscular fatigue after 30 minutes of cycling at 80% of maximal aerobic power, and, on the other hand, that the use of a low (69 rpm) or high (103 rpm) cycling cadence induced a specific neuromuscular adaptation, assessed by the variation in RMS/M wave ratio interpreted as the central neural input change.

From a short distance triathlon race perspective characterised by high cycling or running intensities, these observations raise a major question about the effect of neuromuscular

fatigue and/or metabolic load induced by a prior cycling event on subsequent running performance. To the best of our knowledge, few studies have examined the effect of cycling task characteristics on subsequent running performance.¹⁴⁻¹⁶ Hausswirth *et al*^{15,16} indicated that riding in a continuous drafting position, compared with the no draft modality, significantly reduced oxygen uptake during cycling and improved the performance of a 5000 m run in elite triathletes. In addition, Garside and Doran¹⁴ showed in recreational triathletes an effect of cycle frame ergonomics: when the seat-tube angle was changed from 73° to 81°, the performance of the subsequent 10 000 m run was improved—that is, there was a reduction in race time.

Therefore, the aim of this study was to examine in outdoor conditions the effects of different pedalling cadences (within the range 60–100 rpm) on the performance of a subsequent 3000 m track run, the latter depending mainly on both metabolic and neuromuscular factors.^{17,18}

METHODS

Participants

Nine well motivated male triathletes currently competing at the national level participated in the study. They had been training regularly and competing in triathlons for at least four years. For all subjects, triathlon was their primary activity; their mean (SD) times for Olympic distance and sprint distance triathlons were 120 minutes 37 seconds (3.2) and 59 minutes 52 seconds (3.4) respectively. Mean (SD) training distances a week were 9.1 (1.9) km for swimming, 220.5 (57.1) km for cycling, and 51.1 (8.9) km for running. The mean (SD) age of the subjects was 24.9 (4.0) years. Their mean

Abbreviations: \dot{V}_{O_2} , oxygen uptake; HR, heart rate; \dot{V}_E , ventilatory efficiency; \dot{V}_{O_2MAX} , maximal oxygen uptake

Table 1 Physiological characteristics of the subjects obtained during a maximal cycling test

Parameters	$\dot{V}O_{2MAX}$	$\dot{V}E_{MAX}$	HR _{max}	VT (% $\dot{V}O_{2MAX}$)	MAP
	68.1 (6.5)	179.1 (14.7)	185.4 (4.9)	67.0 (3.6)	398.1 (24.5)

Values are expressed as mean (SD).

$\dot{V}O_{2MAX}$, maximal oxygen uptake (ml/min/kg); $\dot{V}E_{MAX}$, maximal ventilation (litres/min); HR_{max}, maximal heart rate (beats/min); VT, ventilatory threshold; MAP, maximal power output (W).

(SD) body weight and height were 70.8 (3.8) kg and 179 (3.9) cm respectively. The subjects were asked to abstain from exhaustive training throughout the experiment. Finally, they were fully informed of the content of the experiment, and written consent was obtained before all testing, according to local ethical committee guidelines.

Maximal cycling test

Subjects first performed a maximal test to determine $\dot{V}O_{2MAX}$ and ventilatory threshold. This test was carried out on an electromagnetically braked ergocycle (SRM; Jülich, Welldorf, Germany),^{19,20} on which the handle bars and racing seat are fully adjustable both vertically and horizontally to reproduce the positions of each subject's bicycle. No incremental running test was performed in this study, as previous investigations indicated similar $\dot{V}O_{2MAX}$ values whatever the locomotion mode in triathletes who began the triathlon as their first sport.²¹ [22]

This incremental session began with a warm up of 100 W for six minutes, after which the power output was increased by 30 W a minute until volitional exhaustion. During this protocol, $\dot{V}O_2$, $\dot{V}E$, respiratory exchange ratio, and HR were continuously recorded every 15 seconds using a telemetric system collecting gas exchanges (Cosmed K4_{rev}, Rome, Italy) previously validated by Hausswirth *et al.*²³ $\dot{V}O_{2MAX}$ was determined according to criteria described by Howley *et al.*²⁴—that is, a plateau in $\dot{V}O_2$ despite an increase in power output, a respiratory exchange ratio value of 1.15, or an HR over 90% of the predicted maximal HR (table 1). The maximal power output reached during this test was the mean value of the last minute. Moreover, the ventilatory threshold was calculated during the cycling test using the criterion of an increase in $\dot{V}E/\dot{V}O_2$ with no concomitant increase in $\dot{V}E/\dot{V}CO_2$.²⁵

Cycle-run performance sessions

All experiments took place in April on an outdoor track. Outside temperature ranged from 22 to 25°C, and there was no appreciable wind during the experimental period. Each athlete completed in random order three cycle-run sessions (20 minutes of cycling and a 3000 m run) and one isolated run (3000 m). These tests were separated by a 48 hour rest period. Before the cycle-run sessions, subjects performed a 10 minute warm up at 33% of maximal power.¹³ During the cycling bout

of the cycle-run sessions, subjects had to maintain one of three pedalling cadences corresponding to 60, 80, or 100 rpm. These cycling cadences were representative of the range of cadences selected by triathletes in competition.^{15,26} Indeed, it was recently reported that, on a flat road at 40 km/h, cycling cadences could range from 67 rpm with a 53:11 gear ratio to 103 rpm with a 53:17 gear ratio.²⁶ However, 60 rpm is close to the range of energetically optimal cadence values,¹¹ 80 rpm is near the freely chosen cadence,^{6,8} and 100 rpm is close to the cadence used in a drafting situation.^{15,16}

According to previous studies of the effect of a cycling event on running adaptation,^{2,5} the cycling bouts were performed at an intensity above the ventilatory threshold corresponding to 70% of maximal power output (80% $\dot{V}O_{2MAX}$) and were representative of a sprint distance simulation.^{15,16}

The three cycling bouts of the cycle-run sessions were conducted on the SRM system next to the running track. The SRM system allowed athletes to maintain constant power output independent of cycling cadence. In addition, feedback on selected cadence was available to the subjects via a screen placed directly in front of them.

After cycling, the subjects immediately performed the 3000 m run on a 400 m track. The mean (SD) transition time between the cycling and running events (40.4 (8.1) seconds) was the same as that within actual competition.¹ During the running bouts, race strategies were free, the only instruction given to the triathlete being to run as fast as possible over the whole 3000 m.

Measurement of physiological variables during the cycle-run sessions

$\dot{V}O_2$, $\dot{V}E$, and HR were recorded every 15 seconds with a K4_{RQ}. The physiological data were analysed during the cycling bouts at the following intervals: 5th–7th minute (5–7), 9th–11th minute (9–11), 13th–15th minute (13–15), 17th–19th minute (17–19), and every 500 m during the 3000 m run (fig 1).

Measurement of biomechanical variables during the cycle-run sessions

Power output and pedalling cadence were continuously recorded during cycling bout. During the run, kinematic data were analysed every 500 m using a 10 m optojump system

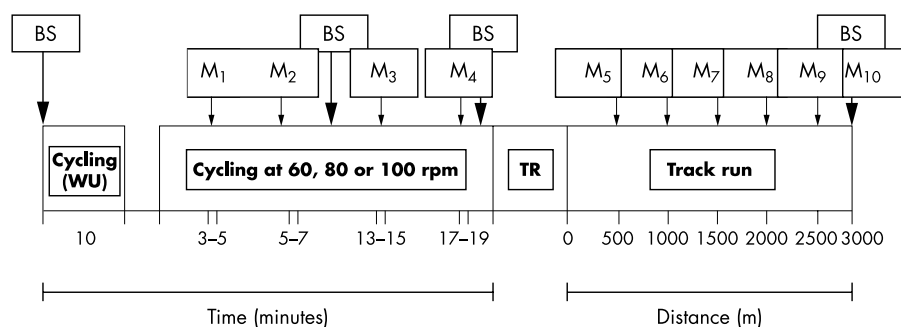


Figure 1 Representation of the three cycle-run sessions. TR, Cycle-run transition; BS, blood samples taken; M₁–M₄, measurement intervals during cycling at 5–7, 9–11, 13–15, and 17–19 minutes; M₅–M₁₀, measurement intervals during running at 500, 1000, 1500, 2500, and 3000 m; WU, warm up for each condition.

Table 2 Mean values for power output and speed, oxygen uptake, expiratory flow, heart rate, blood lactate, and running performance obtained during the cycle-run sessions

Parameter	Cycle (60 rpm)	Run	Cycle (80 rpm)	Run	Cycle (100 rpm)	Run
Power output (W)/speed (km/h)	275.4 (19.4)	17.3 (1.1)	277.1 (18.6)	17.2 (1.20)	277.2 (17.2)	17.1 (1.5)
Oxygen uptake (ml/min/kg)	55.6 (4.6)	62.8 (7.3)*	55.3 (4.0)	57.9 (4.1)	56.5 (4.3)	59.7 (5.6)
Expiratory flow (litres/min)	94.8 (12.2)	141.9 (15.9)	98.2 (9.2)	140.5 (14.6)	107.2 (13.0)*	140.5 (21.8)
Heart rate (beats/min)	163.5 (9.5)	184.2 (4.6)	166.1 (10.4)	185.8 (3.1)	170.7 (4.7)*	182.6 (5.0)
Lactataemia (mmol/l)	4.6 (2.1)	9.0 (1.9)	5.1 (2.1)	9.2 (1.2)	7.0 (2.0)*	9.9 (1.8)
Stride rate (Hz)		1.48 (0.01)		1.49 (0.01)		1.48 (0.02)
Running performance (s)		625.7 (40.1)		630.0 (44.8)		637.6 (57.9)

*Significantly different from the other cycle-run sessions, $p < 0.05$.

(MicroGate, Timing and Sport, Bolzano, Italy). From this system, speed, contact, and fly time attained were recorded every 500 m over the whole 3000 m. The stride rate-stride length combination was calculated directly from these values. Thus the act of measuring the kinematic variables had no effect on the subjects' running patterns within each of the above 10 m optical bands.

Blood sampling

Capillary blood samples were collected from ear lobes. Blood lactate was analysed using the Lactate Pro system previously validated by Pyne *et al.*²⁷ Four blood samples were collected: before the cycle-run sessions (at rest), at 10 and 20 minutes during the cycling bouts, and at the end of the 3000 m run.

Statistical analysis

All data are expressed as mean (SD). The stability of the running pattern was described using the coefficient of variation ($(SD/mean) \times 100$) for each athlete.²⁸ A two way analysis of variance (cadence \times period time) for repeated measures was performed to analyse the effects of time and cycling cadence using $\dot{V}O_2$, $\dot{V}E$, HR, speed velocity, stride variability, speed variability, stride length, and stride rate as dependent variables. For this analysis, the stride and speed variability (in %) were analysed by an arcsine transformation. A Newmann-Keuls post hoc test was used to determine differences among all cycling cadences and periods during exercise. In all statistical tests, the level of significance was set at $p < 0.05$.

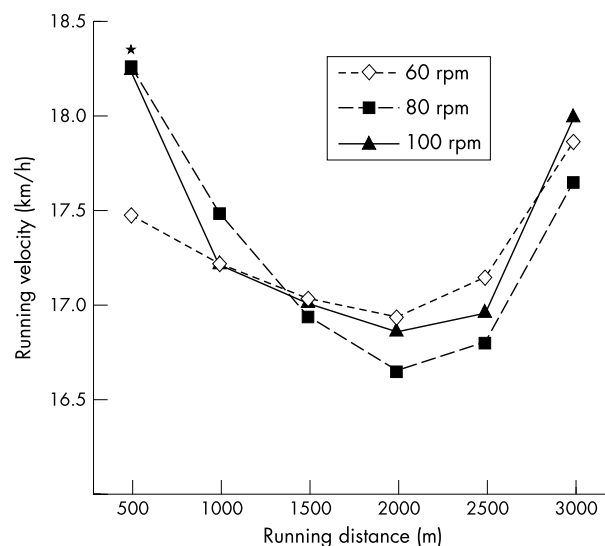


Figure 2 Race strategies expressed as the evolution in running velocity during the run bouts (60, 80, 100 rpm). *Significantly different from the running velocity during the 60 rpm run session, $p < 0.05$.

RESULTS

3000 m performances

In this study, the performance of the isolated run was significantly better than the run performed after cycling (583.0 (28.3) and 631.1 (47.6) seconds for the isolated run and mean cycle-run sessions respectively). No significant effect of cycling cadence was observed on subsequent 3000 m running performance. Running times were 625.7 (40.1), 630.0 (44.8), and 637.7 (57.9) seconds for the 60, 80, and 100 rpm run sessions respectively (table 2). The mean running speed during the first 500 m (fig 2) was significantly lower after the 60 rpm ride than after the 80 and 100 rpm cycling bouts (17.5 (1.1), 18.3 (1.1), and 18.3 (1.2) km/h respectively). In addition, the speed variability (from 500 to 2500 m) was significantly lower during the 60 rpm run session than for the other cycle-run conditions (2.18 (1.2)%, 4.12 (2.0)%, and 3.80 (1.8)% for the 60, 80, and 100 rpm run respectively).

Cycling bouts of cycle-run sessions

During the 20 minutes at 60, 80, and 100 rpm cycling bouts, average cadences were 61.6 (2.6), 82.7 (4.3) and 98.2 (1.7) rpm respectively. Mean HR and $\dot{V}E$ recorded during the 100 rpm cycling bout were significantly higher than in other cycling conditions. Furthermore, blood lactate concentrations were significantly higher at the end of the 100 rpm bout than after the 60 and 80 rpm cycling bouts (7.0 (2.0), 4.6 (2.1) and 5.1 (2.1) mmol/l respectively, $p < 0.05$). Conversely, no effect of either pedalling rate or exercise duration was found on $\dot{V}O_2$ (table 2, $p > 0.05$).

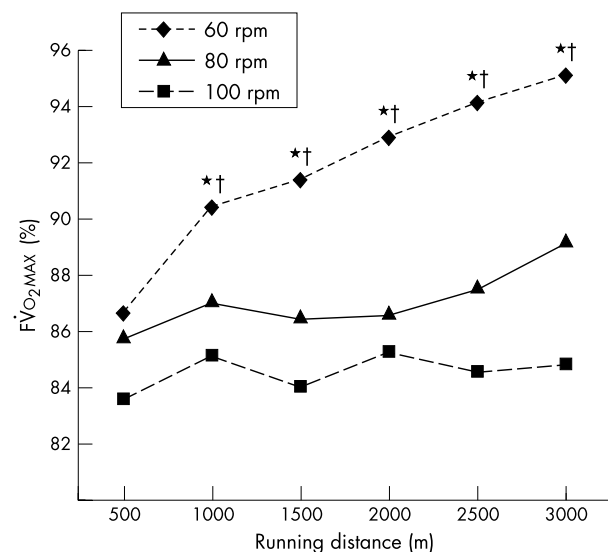


Figure 3 Changes in fraction of $\dot{V}O_{2MAX}$ ($F\dot{V}O_{2MAX}$) sustained by subjects during the running bouts (60, 80, and 100 rpm). *Significantly different from the initial period, $p < 0.05$; †significantly different from the other conditions, $p < 0.05$.

Running bouts of cycle-run sessions

Table 2 gives mean values for $\dot{V}O_2$, $\dot{V}E$, and HR for the running bouts. The statistical analysis indicated a significant interaction effect (period time + cycling cadence) on $\dot{V}O_2$ during subsequent running ($p < 0.05$). $\dot{V}O_2$ values recorded during the run section of the 60 rpm session were significantly higher than during the 80 rpm or the 100 rpm sessions ($p < 0.05$, table 2). These values represent respectively 92.3 (3.0)% (60 rpm run), 85.1 (0.6)% (80 rpm run), and 87.6 (1.2)% (100 rpm run) of cycle $\dot{V}O_{2MAX}$, indicating a significantly higher fraction of $\dot{V}O_{2MAX}$ sustained by subjects during the 60 rpm run session from 1000 to 3000 m than under the other conditions ($p < 0.05$, fig 3). Changes in stride rate within the first 500 m of the 3000 m run were significantly greater during the 80 and 100 rpm run sessions than during the 60 rpm run session (1.52 (0.05), 1.51 (0.05), and 1.48 (0.03) Hz respectively). No significant effect of cycling cadence was found on either stride variability during the run or blood lactate concentration at the end of the cycle-run sessions (table 2).

DISCUSSION

The main observations of this study confirm the negative effect of a cycling event on running performance when compared with an isolated run. However, we observed no effect of the particular choice of cycling cadence on the performance of a subsequent 3000 m run. However, our results highlight an effect of the characteristics of the prior cycling event on metabolic responses and running pattern during the subsequent run.

Cycle-run sessions v isolated run and running performance

To our knowledge only one study has analysed the effect of cycling events on subsequent running performance when compared with an isolated run.¹⁵ The study showed, during a sprint distance triathlon (0.75 km swim, 20 km bike ride, 5 km run), a significant difference between a 5 km run after cycling (alone and in a sheltered position) and the run performed without a prior cycling event (isolated run). The cycling event caused an increase in mean 5 km race time (1014 seconds) and a decrease in mean running velocity (17.4 km/h) compared with the isolated run (980 seconds and 18.2 km/h). Our results are in agreement, showing an impairment in running performance after the cycling event whatever the choice of pedalling cadence. There was an increase in mean running time (631 seconds) and a decrease in mean running velocity (17.2 km/h) compared with the performance in the isolated run (583 seconds and 18.5 km/h). Therefore, one finding of our study is that a prior cycling event can affect running performance over the 3 km as well as the 5 km and 10 km distances.¹⁻²⁹

One hypothesis to explain the alteration in running performance after cycling could be the high metabolic load sustained by subjects at the end of cycling characterised by an increase in blood lactate concentration (4–6 mmol/l) associated with a high $\dot{V}O_{2MAX}$ (81–83%) and HR_{max} (88–92%). On the other hand, Lepers *et al*¹³ have recently shown in well trained triathletes a reduction in muscular force relating to both central and peripheral factors—that is, changes in M wave and EMG RMS—after 30 minutes of cycling performed at different pedalling cadences (69–103 rpm). We hypothesise that these modifications of neuromuscular factors associated with increasing metabolic load during cycling could increase the development of fatigue just before running, whatever the choice of pedalling cadence.

Cycling cadences and physiological and biomechanical characteristics of running

Our results show no effect of different cycling cadences (60–100 rpm) commonly used by triathletes on subsequent

running performance. A classical view is that performance in triathlon running depends on the characteristics of the preceding cycling event, such as power output, pedalling cadence, and metabolic load.¹⁻²⁹ Previous investigations have shown a systematic improvement in running performance when the metabolic load of the cycling event was reduced either by drafting position¹⁵ or racing on a bicycle with a steep seat-tube angle (81°).¹⁴ Unlike a 3000 m run which is characterised by neuromuscular and anaerobic factors,¹⁷⁻¹⁸ the improvement in running performance in these previous studies was observed over a variety of long distances (5–10 km) where the performance depends mainly on the capacity of the subject to minimise energy expenditure over the whole race.¹⁻¹⁴⁻¹⁵⁻²⁹ Therefore one explanation for our results is that minimisation of metabolic load through cadence choice during cycling has a significant effect on the running time mainly during events of long duration. Further research is needed into the effect of cadence choice on total performance for running distances close to those of Olympic and Iron man triathlon events.

However, despite the lack of cadence effect on 3000 m race time, our results indicate an effect of cadence choice (60–100 rpm) on the stride pattern or running technique during a 3000 m run. This difference was mainly related to the higher velocity preferred by subjects immediately after cycling at 80 and 100 rpm and to the lower velocity from 1500 to 2500 m after cycling at high cadences. These results may suggest that the use of a low pedalling cadence (close to 60 rpm) reduces variability in running velocity—that is, one of the factors of running technique—during a subsequent run.

For running speeds above 5 m/s (> 18 km/h) and close to maximum values, the change in stride rate is one of the most important factors in increasing running velocity.³⁰ In our study, the significant increase in running speed observed during the first 500 m of the 80 and 100 rpm run sessions was associated with a significantly higher stride rate (1.51–1.52 Hz) than in the 60 rpm run session (1.48 Hz). The relation between stride rate and cycling cadence has been reported by Hausswirth *et al*¹⁶ in elite subjects participating in a sprint distance triathlon, indicating a significantly higher stride rate after cycling at 102 rpm (1.52 Hz) than after cycling at 85 rpm (1.42 Hz) for the first 500 m of the run.

These observations suggest that immediately after the cycle stage, triathletes spontaneously choose a race strategy directly related to the pedalling cadence, but this effect seems to be transitory, as no significant differences between conditions were reported after the first 500 m of running. This is in agreement with previous studies in which changes in stride pattern and running velocity were found to occur only during the first few minutes of the subsequent run.¹⁻³⁻⁵⁻⁶ Furthermore, the fact that triathletes prefer to run at a high pace after cycling at 80 and 100 rpm seems to confirm different anecdotal reports of triathletes. Most triathletes prefer to adopt a high pedalling cadence during the last few minutes of the cycle section of actual competition. Three strategies may be evoked to characterise the choice of cycling cadence: speeding up in the last part of the cycle stage in order to get out quickly on the run (when elite triathletes compete in draft legal events); reducing power output and spin to minimise the effects of the bike-run transition; maintaining power output while increasing cadence. However, our results show that such a strategy is associated with higher metabolic cost during the cycling stage and greater instability in running pattern, suggesting that it is not physiologically beneficial for the athlete to adopt high pedalling cadences in triathlon competition.

During our study, cycling at 100 rpm was associated with an increase in metabolic cost as classically observed in previous studies for a high cadence such as an increase in $\dot{V}O_2$, HR, $\dot{V}E$,³¹ and blood lactate concentration.⁸ At the end of the 100 rpm cycling task, mean blood lactate concentration was 7.0 (2.0) mmol/l, suggesting a high contribution of anaerobic

Take home message

Compared with an isolated run, completion of a cycling event impairs the performance of a subsequent run independently of the pedalling cadence. However, running strategy, stride rate, and metabolic contribution seem to be improved by the use of a low pedalling cadence (60 rpm). The choice of cycling cadence may have an effect on the running adaptation during a sprint or short distance triathlon.

metabolism,⁸ whereas it was 4.6 (2.1) mmol/l after cycling at 60 rpm. The effect of pedalling rate on physiological adaptation during prolonged cycling has recently been investigated.^{8, 13, 32} Brisswalter *et al*⁸ indicated that cycling at a cadence higher than 95 rpm induces a significant increase in $\dot{V}O_2$, $\dot{V}E$, and lactate concentration after 30 minutes of exercise in triathletes.

Moreover, our results show an effect of cycling cadence on aerobic contribution during maximal running performance. The subjects were able to sustain a higher fraction of $\dot{V}O_{2MAX}$ during the 60 rpm run session—that is, 92%—than during the 80 and 100 rpm run sessions—84% and 87% of $\dot{V}O_{2MAX}$ respectively—(fig 3). These results suggest that the contribution of the anaerobic pathway¹⁷ is more important after the higher cycling rates (80 and 100 rpm) than after the 60 rpm ride and could lead during a prolonged running exercise to earlier appearance of fatigue caused by metabolic acidosis.^{33, 34}

In conclusion, our results confirm the alteration in running performance after a cycling event compared with an isolated run. The principal aim of our investigation was to evaluate the impact of different pedalling rates on subsequent running performance. No significant effect of cycling cadence was found on 3000 m running performance, despite some changes in running strategies, stride rate, and metabolic contributions. We chose a running distance of 3000 m to analyse the possible effect of neuromuscular fatigue—previously reported after a 30 minute cycling exercise at the same intensity¹³—on running performance when neuromuscular and anaerobic factors make important contributions.^{17, 18} As the effect observed was not significant, the choice of cadence within the usual range does not seem to influence the performance of a middle distance run. One limiting factor of this study may be the choice of a short exercise duration because an effect of metabolic load reduction during the cycling stage on running performance was previously observed for a run longer than 5000 m. For multidisciplinary activities such as triathlon and duathlon, further applied research on the relation between cycling cadence and performance of the subsequent run is required to evaluate the influence of the practical conditions and constraints of actual competition.

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COMMENTARY

Much research has been conducted on the effects of cycling on physiological variables measured during subsequent running in triathletes. Few authors, however, have examined the effect of variation in cycling task characteristics on either such variables or overall run performance. This study, examining the effect of different pedalling cadences during a cycle at about

80% $\dot{V}O_{2MAX}$ on performance within a succeeding 3 km run by well trained male triathletes, adds to the published work in this area.

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