Cadence selection affects metabolic responses during cycling and subsequent running time to fatigue

F Vercruyssen, R Suriano, D Bishop, C Hausswirth, J Brisswalter

Methods: Eight triathletes performed, in a laboratory setting, two incremental tests (running and cycling) to determine peak oxygen uptake (VO₂peak) and the lactate threshold (LT), and three cycle-run combinations. During the cycle-run sessions, subjects completed a 30 minute cycling bout (90% of LT) at (a) the freely chosen cadence (FCC, 94 (5) rpm), (b) the FCC during the first 20 minutes and FCC—20% during the last 10 minutes (FCC−20%, 74 (3) rpm), or (c) the FCC during the first 20 minutes and FCC+20% during the last 10 minutes (FCC+20%, 109 (5) rpm). After each cycling bout, running time to fatigue (Tmax) was determined at 85% of maximal velocity.

Results: A significant increase in Tmax was found after FCC−20% (894 (199) seconds) compared with FCC and FCC+20% (651 (212) and 624 (214) seconds respectively). VO₂, ventilation, heart rate, and blood lactate concentrations were significantly reduced after 30 minutes of cycling at FCC−20% compared with FCC+20%. A significant increase in VO₂ was reported between the 3rd and 10th minute of all Tmax sessions, without any significant differences between sessions. Stride pattern and metabolic variables were not significantly different between Tmax sessions.

Conclusions: The increase in Tmax after FCC−20% may be associated with the lower metabolic load during the final minutes of cycling compared with the other sessions. However, the lack of significant differences in metabolic responses and stride pattern between the run sessions suggests that other mechanisms, such as changes in muscular activity, probably contribute to the effects of cadence variation on Tmax.

During triathlon racing (swim/cycle/run), the most critical and strategic aspect affecting overall performance is the change from cycling to running.1,2 These studies have attempted to identify aspects of cycling that may improve running performance in triathletes. Drafting has been shown to be a beneficial cycling strategy which results in an improved subsequent running performance in elite triathletes.3 More recently, the selection of cycling cadence during a cycle-run combination has been identified by researchers as an important variable that may affect overall performance.4,5 Cadence selection has been reported to influence metabolic responses, kinematic variables, and performance during a cycle-run session. However, the extent to which the cadence selection affects subsequent maximal running performance during a cycle-run combination remains unclear.

In a laboratory setting, Vercruyssen et al6 have shown that the adoption of a low cadence (73 rpm), corresponding to the energetically optimal cadence, reduced oxygen uptake (VO₂) during a cycle-run session, compared with the selection of higher cadences (80–90 rpm). These authors suggested that the choice of a low cadence (<80 rpm) before the cycle-run transition may be advantageous for the subsequent run. However, during field based investigations, Gottshall and Palmer7 found an improved 3200 m track running performance after 30 minutes of cycling conducted at a high cadence (>100 rpm) compared with lower cadences (70–90 rpm) for a group of triathletes. It was suggested that the selection of a high cadence improved running performance through increased stride rate and running speed during the subsequent run. In contrast, Bernard et al8 showed no effect of cycling cadence (60–100 rpm) and stride rate on a subsequent 3000 m running performance. These conflicting results indicate the difficulty of predicting the optimal cadence selection for a cycle-run session in trained triathletes.

In most of the above experiments, the triathletes were required to cycle at either an imposed cadence (range 60–110 rpm) or a freely chosen cadence (range 80–90 rpm) which remained constant for the entire 30 minutes of the cycle bout. This lack of cadence variation does not reproduce race situations, during which the cadence may vary considerably especially before the cycle-run transition.1 Many triathletes attempt to optimise the change from cycling to running by selecting high cadences (>100 rpm) during the final kilometres of cycling.1,2,4 Another strategy, however, may be the selection of a low cadence (~75 rpm) before the cycle-run transition, in order to conserve energy for the subsequent run.1,4 To our knowledge, no data are available on cadence changes during the last few minutes before the cycle-run transition and its effects on subsequent running performance.

Therefore the aim of this investigation was to examine, in a laboratory setting, the effect of cadence variations during the final 10 minutes of cycling on metabolic responses, stride pattern, and subsequent running time to fatigue in triathletes.

METHODS
Participants
Eight experienced male triathletes currently in training volunteered to take part in this experiment. All had regularly competed in triathlon racing at either sprint (0.750 km swim/20 km cycle/5 km run) or Olympic distances (1.5 km swim/40 km cycle/10 km run) for at least five years. Mean (SD) training distances a week were 11.1 (2.2) km in swimming, 285.7 (90.0) km in cycling, and 42.1 (12.9) km in running.

Abbreviations: FCC, freely chosen cadence; HR, heart rate; [La]ₗ, lactate concentration; LT, lactate threshold; P_max, maximal power output; V_max, maximal running speed; VE, minute ventilation; VO₂, oxygen uptake; VO₂peak, peak oxygen uptake; VO₂SC, VO₂ slow component
Table 1  Peak exercise responses of triathletes

<table>
<thead>
<tr>
<th>Variable</th>
<th>Cycling</th>
<th>Running</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO2PEAK (ml/min/kg)</td>
<td>67.6 (3.6)</td>
<td>68.9 (4.6)</td>
</tr>
<tr>
<td>VO2peak (l/min)</td>
<td>4.9 (0.4)</td>
<td>5.0 (0.5)</td>
</tr>
<tr>
<td>VO2 at LT (l/min)</td>
<td>3.8 (0.4)</td>
<td>4.4 (0.5)*</td>
</tr>
<tr>
<td>HRpeak (beats/min)</td>
<td>176 (8)</td>
<td>182 (10)*</td>
</tr>
<tr>
<td>[l-a] peak (mmol/l)</td>
<td>14.2 (2.1)</td>
<td>10.4 (3.1)*</td>
</tr>
<tr>
<td>Pmax (W)/Vmax (km/h)</td>
<td>395 (34)</td>
<td>19.5 (9.9)</td>
</tr>
</tbody>
</table>

Values are mean (SD). *Significantly different from running, p<0.05.

Maximal tests

Two incremental tests were used to determine peak oxygen uptake (VO2PEAK), maximal power output (Pmax), maximal running speed (Vmax), and lactate threshold (LT). Subjects performed cycling bouts on a racing bicycle mounted on a stationary turbo-trainer system. Variations in power output were measured using a "professional" SRM crankset (Schoberer Rad Messtechnik, Fuchsend, Germany) previously validated in a protocol comparison using a motor driven friction brake. Running bouts were performed on a motorised treadmill situated next to the cycle turbo-trainer.

For cycling, the test bout began at an initial load of 100 W for three minutes, after which the power output was increased by 40 W every three minutes until exhaustion. For the treadmill test, the initial running speed was fixed at 9 kph, with an increase in velocity of 1.5 kph every three minutes. For both cycling and running tests, there was a one minute rest period between each increment for the sampling of capillary blood (35 μl) from the hyperaemic earlobe. Blood samples were collected to determine plasma lactate concentration ([l-a]−) using a blood gas analyser (ABL 625; Radiometer Medical A/S, Copenhagen, Denmark).

During these tests, VO2, VE, and respiratory exchange ratio were continuously recorded every 15 seconds using Ametek gas analysers (SOV S-3A and COV CD3A; Pittsburgh, Pennsylvania, USA). The four highest consecutive VO2 values were summed to determine VO2PEAK. Pmax and Vmax were calculated as the average power output and running speed in the last three minutes completed before exhaustion. Heart rate (HR) was monitored every 10 seconds during each experimental session using an electronic HR device with a chest electrode (Polar Vantage NV; Polar Electro Oy, Kempele, Finland). The LT calculated electronic HR device with a chest electrode (Polar Vantage

3–5 min 93 (5) 264 (30)
20–22 min 75 (3)† 262 (28)
28–30 min 74 (4)† 262 (25)
FCC
3–5 min 94 (5) 264 (30)
20–22 min 94 (5)† 264 (29)
28–30 min 95 (5)† 265 (30)
FCC+20% 3–5 min 91 (4) 263 (30)
20–22 min 104 (8)† 259 (27)
28–30 min 109 (6)† 262 (30)

Values are mean (SD). *Significantly different from the first 20 minutes, p<0.05. †Significantly different from the other conditions at the same time period, p<0.05.

Cycle-run combinations

All triathletes completed, in random order, three cycle-run sessions each composed of 30 minutes of cycling, on a cycle turbo-trainer, and a subsequent run to fatigue. A fan was used in front of the subject during these experimental sessions. Before each experimental condition, subjects performed 15 minutes of warm up comprising 13 minutes at a low power output (100–130 W) and the last two minutes at the individual workload required during the cycle bout of cycle-run sessions. After two minutes of rest, each triathlete completed a cycle bout at (a) the freely chosen cadence (FCC), (b) the FCC during the first 20 minutes and FCC—20% during the last 10 minutes (FCC—20%), or (c) the FCC during the first 20 minutes and FCC+20% during the last 10 minutes (FCC+20%). The FCC±20% range has previously been used during a 30 minute cycling exercise in triathletes. Cycling bouts were performed at a power output corresponding to 90 % of LT (266 (28) W) and represented an intensity close to that reported in previous studies of the relation between cycling cadence and running performance. FCC—20% was chosen to replicate cadence values close to the energetically optimal cadence previously noted in triathletes, and FCC+20% allowed us to reproduce cadence values close to those reported during cycling strategies before running. Cadence and power output were monitored using the SRM power meter during all cycling bouts. No feedback was given to the subjects on their FCC over the three conditions.

After each cycling bout, running time to fatigue (Tmax) was determined on the treadmill at a running speed corresponding to 85% of Vmax (>LT) for each athlete (16.7 (0.7) kph). On the basis of previous experiments and the completion of pilots tests, this running intensity was chosen to induce fatigue in less than 20 minutes. All subjects were given verbal encouragement throughout each trial. The Tmax was taken as the time at which the subject’s feet left the treadmill as he placed his hands on the guardrails. The transition time between running and cycling was fixed at 45 seconds to reproduce the racing context.

Measurement of metabolic variables

VO2, VE, and HR were monitored and analysed during the following intervals: 3rd–5th minute of cycling bout (3–5 min), 20th–22nd minute (20–22 min), 28th–30th minute (28–30 min) and every minute during the running sessions. Five blood samples were collected at the following intervals: before the warm up, at 5, 20, and 30 minutes during cycling, and at the end of Tmax.

Measurement of kinematic variables

Power output and cycling cadence were continuously recorded during the cycling bouts. For each running session, a 50 Hz digital camera was mounted on a tripod 4 m away from the motorised treadmill. Subsequently, the treadmill
combinations. Differences in T max obtained between the three experiments were analysed by one way analysis of variance. A paired t test was used to analyse differences in VO2PEAK, HRpeak, and VO2 at LT between the two maximal tests. Statistical significance was set at p<0.05.

RESULTS

Maximal tests

No significant differences in VO2PEAK were observed between the sessions (table 1). However, HRpeak and VO2 at LT were significantly higher during running than during the maximal cycling bout (+2.9% and +15.8% respectively).

Cycling bouts of cycle-run sessions

No significant variation in FCC was observed during the first 20 minutes of the three cycling bouts (table 2). In addition, mean power output values were not significantly different between the cycling bouts (264 (30), 263 (28), and 261 (29) W respectively for FCC, FCC–20%, and FCC+20%). These data show that subjects adhered to the experimental design with respect to the required power output-cadence combination.

A significant effect of exercise duration (between 3–5 and 28–30 min intervals) was observed on VO2, VE, and HR during the FCC and FCC+20% bouts whereas no significant variation in these metabolic variables was identified with exercise duration during the FCC–20% condition (table 3). Moreover, mean VO2, VE, and HR were significantly lower at FCC–20% compared with FCC+20% during the 28–30 min interval (respectively, −5.3%, −18.2%, and −6.8%). [La−] was significantly higher during the 28–30 min interval at FCC+20% compared with FCC (+3.2%) or FCC–20% (+5.5%).

Running bouts of cycle-run sessions

A significant increase in Tmax was observed only after the FCC–20% modality when compared with both the FCC+20% and FCC conditions (+43.3% and +37.3% respectively; fig 1). Tmax values were 624 (214), 651 (212) and 894 (199) seconds after the FCC+20%, FCC and FCC–20% modalities respectively. A significant increase in ΔVO2—that is, between the 3rd and 10th minute—was found during the Tmax completed after FCC (+6.1%), FCC+20% (+6.7%), and FCC–20% (+6.5%) (table 4). However, mean VO2, VE, HR, and [La−] were not significantly different between the three Tmax sessions (table 4).

No significant difference in stride pattern was observed during the Tmax sessions whatever the prior cadence selection (fig 2). Mean stride rate (Hz) and stride length (m) were 1.49 (0.01) and 3.13 (0.02) after FCC, 1.48 (0.01) and 3.13 (0.03) after FCC+20%, and 1.49 (0.01) and 3.15 (0.02) after the Tmax sessions subsequent to the FCC, FCC–20% and FCC+20% bouts respectively.

DISCUSSION

The main findings of this investigation show a significant increase in Tmax when the final 10 minutes of cycling is performed at FCC–20% (894 seconds) compared with FCC (651 seconds) and FCC+20% (624 seconds). Several hypotheses are proposed to explain the differences in Tmax reported.
obtained at Tmax – 2 min. It has previously been reported that metabolic
previously reported during an exhaustive isolated run
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Tmax;T, Stride rate obtained at
Variations in stride rate during the running time to fatigue
Figure 2
The Tmax values of this investigation are comparable to those
Metabolic hypotheses
The Tmax values of this investigation are comparable to those
previously reported during an exhaustive isolated run.1 For instance, during a running session after cycling, a
substantial increase in energy cost, VE, and HR, and differences in muscle blood flow have been observed
with an isolated run.1 3 5 6 Moreover, variations in running kinematics such as stride rate, segmental angular
position, and joint angle have been shown after a cycle bout.1 5 6 These running alterations, which have been linked to
the effects of exercise duration and cycle-run transition, were
reported during treadmill sessions conducted at a submaximal intensity and not during a high intensity running bout.
In this study we investigated these effects at a high intensity close to a running speed previously observed during a short
cycle-run combination in triathletes.6

<table>
<thead>
<tr>
<th>Variable</th>
<th>Run after FCC – 20%</th>
<th>Run after FCC</th>
<th>Run after FCC – 20%</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO2 (ml/min/kg)</td>
<td>63.9 (2.7)</td>
<td>62.0 (2.8)</td>
<td>61.8 (1.4)</td>
</tr>
<tr>
<td>VO2 (l/min)</td>
<td>4.72 (0.4)</td>
<td>4.59 (0.4)</td>
<td>4.56 (0.3)</td>
</tr>
<tr>
<td>VO2 (10–3 min)(ml/min)*</td>
<td>291.3 (126.5)</td>
<td>269.9 (123.5)</td>
<td>291.3 (114.5)</td>
</tr>
<tr>
<td>VE (l/min)</td>
<td>122.5 (15.8)</td>
<td>122.0 (13.3)</td>
<td>122.8 (10.8)</td>
</tr>
<tr>
<td>HR (beats/min)</td>
<td>169 (8)</td>
<td>169 (10)</td>
<td>168 (10)</td>
</tr>
<tr>
<td>[La] (mmol/l)</td>
<td>6.8 (1.7)</td>
<td>7.4 (2.1)</td>
<td>7.2 (2.2)</td>
</tr>
</tbody>
</table>

Values are expressed as mean (SD).
*Significantly different between the 3rd and 10th minute of exercise, p<0.05.

During the various cycle-run combinations for the group of triathletes.
A number of studies have analysed characteristics of cycle-
run sessions in triathletes, with particular focus on physio-
logical and biomechanical aspects during the subsequent run.1 For instance, during a running session after cycling, a
substantial increase in energy cost, VE, and HR, and differences in muscle blood flow have been observed
with an isolated run.1 3 5 6 Moreover, variations in running kinematics such as stride rate, segmental angular
position, and joint angle have been shown after a cycle bout.1 5 6 These running alterations, which have been linked to
the effects of exercise duration and cycle-run transition, were
reported during treadmill sessions conducted at a submaximal intensity and not during a high intensity running bout.
In this study we investigated these effects at a high intensity close to a running speed previously observed during a short
cycle-run combination in triathletes.6

Metabolic hypotheses
The Tmax values of this investigation are comparable to those
previously reported during an exhaustive isolated run performed at an intensity corresponding to 85–90%
VO2MAX.11–13 It has previously been reported that metabolic and muscular factors are potential determinants of middle
distance running performance and/or exhaustive treadmill sessions in trained subjects.16–20 With respect to metabolic
factors, the improvement in Tmax observed after FCC–20% may be related to changes in energy contribution. In support
of this hypothesis, it has been reported that the determinants of maximal performances in middle distance running may be
linked to the energy requirement for a given distance and the
maximal rate of metabolic energy output from the integrative contribution of aerobic and anaerobic systems.15 18 During
submaximal and maximal running, the VO2 variation has
been reported to reflect the relative contribution from the aerobic and anaerobic sources.15 In the context of a cycle-run
session, Bernard et al8 have reported that triathletes were able to sustain a higher fraction of VO2MAX during a 3000 m track
run performed after cycling at 60 rpm than during cycling at 80 and 100 rpm. These authors suggested that a greater
contribution of the aerobic component, during running after the choice of a low cadence, may delay fatigue for longer
running distances. In this investigation, the analysis of VO2 may also provide information on possible changes in aerobic
contribution during high intensity running. Given the range of Tmax values, the metabolic variables were analysed during
the first 10 minutes of each running session, corresponding
approximately to the mean Tmax values reported after the
FCC and FCC+20% modalities (fig 1). The evaluation of this
time interval indicates no significant differences in VO2
between the Tmax sessions, suggesting that the determination of Tmax in this study was not affected by changes in metabolic
energy from the aerobic or anaerobic systems.

There was, however, a significant increase in VO2 between
the 3rd and 10th minute (6.1–6.7%) during the three Tmax
sessions, regardless of the prior experimental condition
(table 4). During exercise lasting less than 15 minutes, the
continual rise in VO2 beyond the 3rd minute has been termed the
VO2 slow component (VO2SC).5 11 19 20 The occurrence of a
VO2SC is classically observed during heavy running and
cycling exercises associated with a sustained lactic acido-
sis—that is, above the LT.19 21 22 Postulated mechanisms
responsible for this VO2SC include rising muscle temperature
(Q10 effect), cardiac and ventilatory muscle work, lactate
kinetics, catecholamines, and recruitment of less efficient
type II muscle fibres.26 Within this framework, Yano et al23
suggested that muscular fatigue may be one of the factors
that produce the development of a VO2SC during high
intensity cycling exercise.

However, several investigators have examined the influ-
ence of prior exercise on the VO2 response during subsequent
exercise:24–26 Burnley et al24 showed that the magnitude of VO2
kinetics during heavy exercise was affected only by a prior
during heavy exercise, muscle perfusion and/or O2 off loading at the
muscle may be improved, resulting in changes in VO2 kinetics
during the second bout of exercise.25 26 In addition, changes in
the VO2 response may be accentuated by the manipulation
of cadence during an isolated cycling bout.27 Gotshall et al27
showed an increase in muscle blood flow and a decrease in
systemic vascular resistance with increasing cadence (from

![Figure 2](https://www.bjsportmed.com)

Figure 2 Variations in stride rate during the running time to fatigue
after the selection of various cycling cadences. T, Stride rate obtained at
Tmax; T–1, stride rate obtained at Tmax–1 min; T–2, stride rate
obtained at Tmax–2 min.)
What is already known on this topic

Various characteristics of cycle-run sessions in triathletes have been studied, with particular focus on physiological and biomechanical aspects during the subsequent run. During a running session after cycling, a substantial increase in energy cost, minute ventilation, and heart rate, and differences in muscle blood flow have been observed compared with an isolated run. Moreover, variations in running kinematics such as stride rate, segmental angular position, and joint angle have been shown after a cycle bout.

Muscular and stride pattern hypotheses

Although we conducted no specific analysis of muscular parameters, an attractive hypothesis to explain the differences in $T_{\text{max}}$ between conditions is that they are due to differences in the muscular activity or fatigue state during cycle-run sessions. Muscular contractions differ during cycling and running. Cycling is characterised by longer phases of concentric muscular contraction, whereas running involves successive phases of eccentric-concentric muscular action. Muscle activity during different modes of contrac-
tion can be assessed from the variation in the electromyo-
graphic signal. In integrated electromyography based investigations, it has been shown that muscles such as the gastrocnemius, soleus, and vastus lateralis are substantially activated during running. Any alterations in the contractile capability of these muscles may have affected the ability to complete a longer $T_{\text{max}}$ during the cycle-run sessions in this study.

Furthermore, many studies have reported substantial changes in muscular activity during isolated cycling exercises, especially when cadence is increased or decreased. With respect to the cycle-run combination, the manipulation of cadence may accentuate modifications in muscular activity during cycling and influence the level of fatigue during a subsequent run. Marsh and Martin showed a linear increase in electromyographic activity of the gastrocnemius and vastus lateralis muscles when cadences increased from 50 to 110 rpm. Although activity of the gastrocnemius muscle has been shown to increase considerably more than the soleus muscle as cadence is increased, Ericson et al have also reported a significant increase in soleus muscle activity with the selection of high cadences. These results from isolated cycling exercises conducted in a state of non-fatigue suggest that, during the last 10 minutes of the cycling bout of our study, there was greater recruitment of the vastus lateralis, gastrocnemius, and soleus muscles after cycling at higher cadences. This may have resulted in an increase in fatigue of these muscles, which are substantially activated during subsequent running. In contrast, the lower activity of the vastus lateralis, gastrocnemius, and soleus muscles after the FCC condition may have reduced the fatigue experienced during cycling and resulted in improved utilisation of these muscles during the subsequent run. This may have contributed to the observed increase in $T_{\text{max}}$ for this condition. Nevertheless, Lepers et al suggested that the neuromuscular fatigue observed after 30 minutes of cycling was attributable to both central and peripheral factors but was not influenced by the pedalling rate in the range 70–110 rpm. Although activity of the gastrocnemius muscle increased during running cadence during a prior cycle bout could attenuate the magnitude of $V\text{O}_{2\text{SC}}$ during subsequent running.

In contrast with these earlier studies, the $V\text{O}_{2\text{SC}}$ values of this investigation were not significantly different between trials during the first 10 minutes of exercise between the $T_{\text{max}}$ sessions. This was observed despite differences in metabolic load and cadence selection during the previous cycling bouts. These results indicate that the adoption of FCC–20% is associated with a reduction in metabolic load with exercise duration, but does not affect the $V\text{O}_{2\text{SC}}$ during the subsequent run. For instance, the selection of FCC–20% is associated with a significant reduction in $V\text{O}_{2}$ (–5.3%), VE (–18.2%), HR (–6.8%), and [La$^-$] (–55.5 %) during the final 10 minutes of cycling compared with FCC+20%, without any significant changes in $V\text{O}_{2\text{SC}}$ during subsequent running between the two conditions. This suggests that the chosen cadences do not affect the $V\text{O}_{2}$ responses during the subsequent run and also that the occurrence of a $V\text{O}_{2\text{SC}}$ does not contribute to the differences in $T_{\text{max}}$ found in this study. This is consistent with previous research on trained sub-
jects.

What this study adds

This study shows that the choice of a low cadence during the final minutes of cycling improves subsequent running time to fatigue.
that metabolic responses related to $\text{VO}_2$ do not explain the differences in running time to fatigue. However, the effect of cadence selection during the final minutes of cycling on muscular activity requires further investigation. From a practical standpoint, the strategy to adopt a low cadence before running, resulting in a lower metabolic load, may be beneficial during a sprint distance triathlon.

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Authors' affiliations

F Vercruyssen, J Brisswalter, Department of Sport Ergonomics and Performance, University of Toulon-Var, BP 132, 83957 La Garde cedex, France.

R Suriano, D Bishop, School of Human Movement and Exercise Science, University of Western Australia, Crawley, WA 6009, Australia.

C Hausswirth, Laboratory of Physiology and Biomechanics, Nationale Institute of Sport and Physical Education, 11, avenue du Tremblay, 75 012 Paris, France.

Competing interests: none declared

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