Journal of Strength and Conditioning Research, 2000, 14(1), 97–101
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Acute Effects of Cycling on Running Step Length and Step Frequency

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ABSTRACT

This study determined the acute effects of an intense cycling bout on running kinematics (step length and step frequency) and on running performance (speed and efficiency). Ten male triathletes completed 2 sessions of testing on separate days. During the first session (the cycle/run condition), the participants completed a 30-minute high-intensity cycling bout, immediately followed by a 5-km run at race effort. For the second session (run/run condition), the participants completed a 30-minute high-intensity running bout at the heart rate measured during the cycling bout, immediately followed by a 5-km run at race effort. Analysis indicated that immediately following the cycling bout, the participants ran with a smaller step length (SL) and a higher step frequency (SF). However, as the cycle/run condition 5-km run progressed, the participants ran with increasing SL, decreasing SF, increasing speed, and increasing efficiency in comparison with the measurements of the run/run condition. Practically, measurements of running kinematics and running performance after cycling differed from measurements taken immediately after running. Therefore, the notion that running form differs after cycling is not merely an individual athlete's perception, but a valid observation.

Key Words: triathlon, duathlon, transitions, biomechanics, perseveration, central pattern generator

Reference Data: Gottschall, J.S., and B.M. Palmer. Acute effects of cycling on running step length and step frequency. *J. Strength Cond. Res. 14(1):97–101. 2000.*

Introduction

During the transition from cycling to running, multisport athletes such as triathletes and duathletes dismount their bikes, remove their helmets, change their shoes, and start the run. These athletes frequently assert that their running form immediately after cycling is awkward; specifically, competitors complain about an inability to pursue a consistent rhythm and maintain a constant pace (12); additionally, they report that their legs feel heavy from fatigue (3).

Researchers have studied the physiological changes, including those affecting heart rate, oxygen consumption, and blood lactate, during a running bout that followed a cycling bout. Heart rate and oxygen consumption were found to increase significantly immediately after the transition from cycling to running (13). Moreover, blood lactate levels were higher during a maximal run that followed a controlled running bout compared with a maximal run that followed a cycling bout (13).

In addition, prior research does imply that stride length and stride frequency contribute to running performance. The investigations referred to these parameters as possible controlling factors of fatigue, running economy, and mechanical efficiency. Fatigue caused runners to systematically alter their technique throughout a race by decreasing both stride length and stride frequency (11), by modifying running economy through gait kinetics and the speed of movement (7), and by manipulating mechanical efficiency through running stride alterations (5).

Lay publications offer nonscientific advice about what causes these physiological modifications and how to improve performance by cycling and running consecutively in training. However, no previous research has specifically determined that running kinematics are affected by cycling or that prior exercise initiates a slower pace. Thus, the purpose of this study was to determine the differences, if any, in step length (SL) and step frequency (SF) and in speed and efficiency in a maximal 5-km run after a cycling bout compared with a maximal 5-km run after a controlled running bout.

Methods

Participants

Ten male triathletes, age 20–25 years, volunteered for this study. Each participant was a member of the University of Colorado Triathlon Team and had various levels of racing experience. Table 1 indicates the participants' age, height, weight, transition time, and racing experience. All participants signed an informed consent that followed the guidelines of the University of Colorado Human Use Committee.

Table 1. Descriptive statistics of participants.

Parameter	Mean ± *SD*
Age (y)	23 ± 1
Height (m)	1.83 ± 0.05
Weight (kg)	73 ± 4
Transition time (min)	0.79 ± 0.21
Number of sprint distance triathlons	14 ± 5

Procedures

Each participant completed 2 testing conditions on separate days. During the first session of testing—the cycle/run condition—each participant completed a 30-minute high-intensity cycling bout, immediately followed by a 5-km run at race effort. During the second session of testing—the run/run condition—each participant completed a 30-minute high-intensity running bout, maintaining the same heart rate he had had in the first session's cycling bout, immediately followed by a 5-km run at race effort. The run/run condition was performed 7–10 days after the cycle/run condition.

Each participant performed the cycling bout on his individual racing bike, with clipless pedals mounted to a stationary windtrainer (Performance Corporation, Chapel Hill, NC). Heart rate (HR) was monitored during both testing sessions with a Polar Accurex II electronic heart rate device with a chest electrode (Polar Electronics, Woodbury, NY). The participants rated their perceived exertion using the Borg method (2).

Session 1: Cycle/Run Condition. The cycling bout was divided into three 10-minute stages of fixed cadence and increasing intensity. For the first stage, the participants were instructed to cycle at a warm-up pace. For the second stage, the participants were instructed to increase their intensity, which corresponded to an increase in HR of 20–30 beats per minute (bpm). For the third stage, the participants were informed that their HR should increase by another 20–30 bpm.

At the conclusion of the third cycling stage, the participants dismounted from their bikes, removed their cycling gear, and put on running shoes. The participants were instructed to perform their accustomed efficient routine for transitioning from cycling to running. The transition time is the number of seconds for each individual to complete this routine. Each participant then ran a 5-km run by completing 12.5 laps on a standard 400-m track.

Session 2: Run/Run Condition. The HR recordings of the cycling bout from the cycle/run condition determined the intensity of the initial 30-minute run. Consequently, the initial running bout was divided into 3 stages, with HR during each stage matching HR measurements recorded during the cycle/run condition.

At the conclusion of the 30-minute run and after waiting for the amount of transition time noted from the cycle/run condition, each participant then ran a 5-km run by completing 12.5 laps on a standard 400-m track.

Dependent Measures

Before each trial began, the track was prepared for the measurement of SL and SF by the application of 2 patches of white powder, each approximately 0.5 m × 1 m in area; the patches were 41.5 m (136 ft) apart.

For every odd-numbered lap of the 5-km run, the participants were instructed to run through the powder patches while reporting HR and rate of perceived exertion (RPE). As the right foot struck the first patch of powder, a stopwatch was started. As the right foot struck the second patch of powder, the stop watch was stopped. The number of steps was counted, the distance between the powder patches was measured, and the time interval was recorded.

SL was defined as the mean distance from the footstrike of 1 foot in the first powder patch to the footstrike of another foot in the second powder patch; mean SL was calculated by dividing the distance between the 2 marks by the number of corresponding steps. SF was defined as the number of footstrikes in a second and measured by dividing the number of steps between the 2 marks by the number of seconds in the corresponding recorded time interval. Speed was calculated as the product of SL ($m \cdot step^{-1}$) and SF ($steps \cdot s^{-1}$). Efficiency was calculated as the ratio of speed ($m \cdot s^{-1}$) to heart rate ($beats \cdot s^{-1}$).

Statistical Analysis

Repeated-measures analysis of variance (ANOVA) was used to analyze the data for SL, SF, speed, and efficiency. The design was a 2 × 7 factorial with condition (cycling, running) and lap number (1, 3, 5, 7, 9, 11, 13) as factors. The data were considered significantly different when the probability of Type I error (*p*-value) was less than 0.05. Post hoc analyses of significant means and appropriate interactions were performed using a Tukey test for simple effects.

Results

Figure 1 represents the participants' mean SL calculated as meters per step ($m \cdot step^{-1}$) during each 5-km run at race effort. Repeated-measures ANOVA revealed that there was not a significant main effect for condition but that there was a significant main effect for lap number. In addition, there was a significant interaction between condition and lap number ($p < 0.01$), indicating a difference in the sensitivity of the conditions to the increasing distance. Specifically, there was more of an increase in SL over the 5-km run after cycling.

Figure 2 illustrates the participants' mean SF calculated as steps per second ($step \cdot s^{-1}$) during each 5-

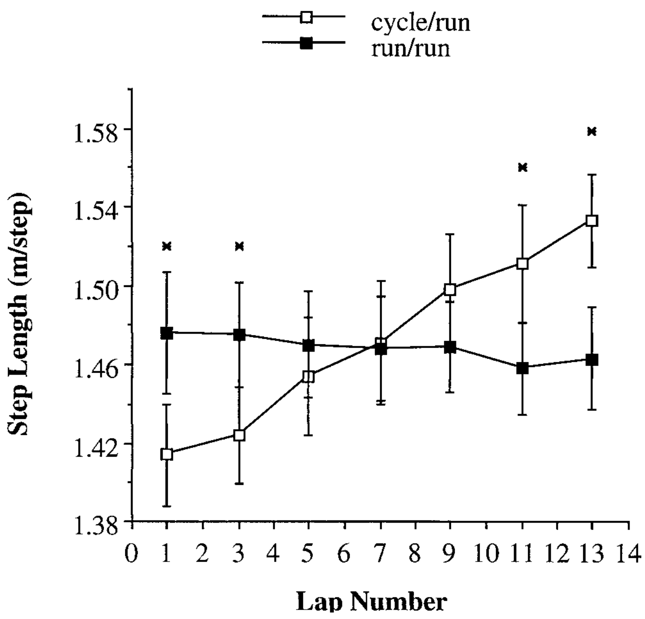

Figure 1. Step length (SL) during the 5-km run at race effort for the cycle/run condition and for the run/run condition. SL after cycling was initially lower than SL after running. Asterisk (*) indicates a significant difference ($p < 0.05$) in values between conditions for a given lap number. There was a significant interaction between condition and lap number ($p < 0.01$).

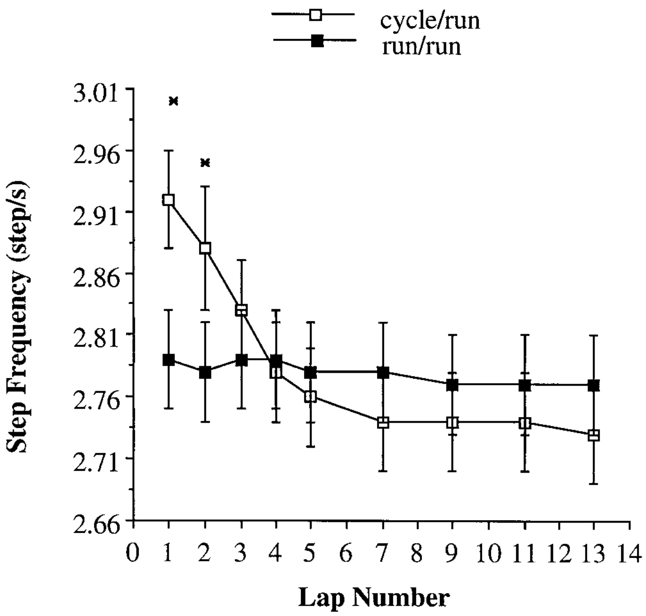

Figure 2. Step frequency (SF) during the 5-km run at race effort for the cycle/run condition and for the run/run condition. SF after cycling was higher than SF after running during the first half of the 5-km run. Asterisk (*) indicates a significant difference ($p < 0.05$) in values between conditions for a given lap number. There was a significant interaction between condition and lap number ($p < 0.0001$).

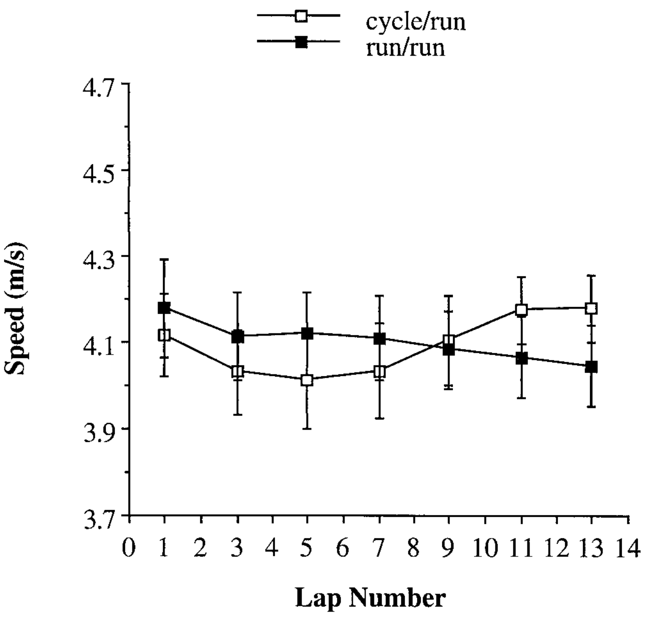

Figure 3. Speed during the 5-km run at race effort for the cycle/run condition and for the run/run condition. There was a significant interaction between condition and lap number ($p < 0.0001$).

km run at race effort. Repeated-measures ANOVA did not indicate a significant main effect for condition; however, the main effect for lap number was significant, and the interaction of condition and lap number was significant ($p < 0.0001$). Specifically, SF decreased significantly over the 5-km run after cycling.

Figure 3 represents the participants' mean speed calculated in meters per second ($m \cdot s^{-1}$) during each 5-km run at race effort. The repeated-measures ANOVA revealed that there was not a significant main effect for either condition or lap number; however, the interaction of condition and lap number was significant ($p < 0.0001$).

Figure 4 presents the participants' mean efficiency values, which demonstrate the relationship between speed and heart rate, calculated as meters per beat during each 5-km run at race effort. Repeated measures ANOVA indicated that there was a significant main effect across laps but not across conditions. The interaction of condition and lap number was significant ($p < 0.0001$).

The mean HR recordings gradually increased after both the cycling bout (lap 1 = 177 bpm; lap 13 = 182 bpm) and the running bout (lap 1 = 176 bpm; lap 13 = 186 bpm). The repeated-measures ANOVA for HR did not demonstrate significant main effects for condition; however, it did illustrate significant main effects for lap number ($p < 0.0001$) and for the interaction of condition and lap number ($p < 0.05$).

The mean RPE recordings gradually increased after both the cycling bout (lap 1 = 16; lap 13 = 18) and the running bout (lap 1 = 16; lap 13 = 19) . The re-

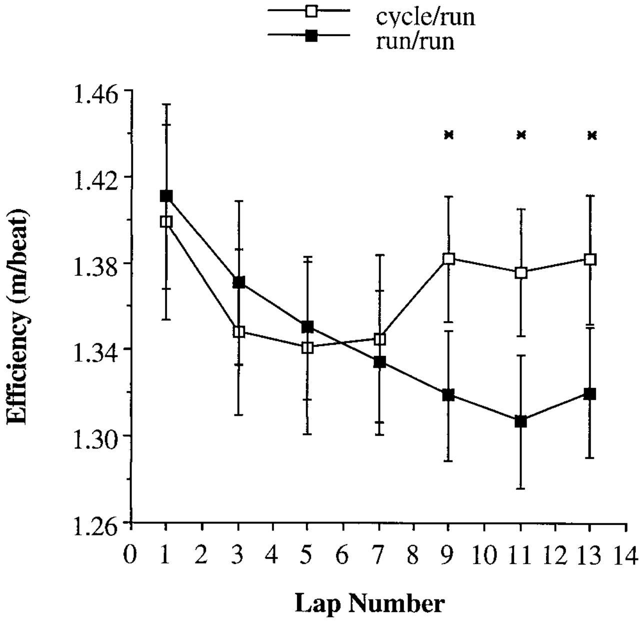

Figure 4. Efficiency during the 5-km run at race effort for the cycle/run condition and for the run/run condition. Efficiency after cycling gradually increased above efficiency after running at the conclusion of the 5-km run. Asterisk (*) indicates a significant difference ($p < 0.05$) in values between conditions for a given lap number. There was a significant interaction between condition and lap number ($p < 0.05$).

peated-measures ANOVA for RPE did not demonstrate significant main effects for condition; however, it did illustrate significant main effects for lap number ($p < 0.01$) and for the interaction of condition and lap number ($p < 0.05$).

Discussion

The findings of this study demonstrate that running kinematics immediately after a cycling bout differed from those immediately after a running bout, especially during the first 2 km of the 5-km run at race effort. Specifically, (a) SL after cycling was initially lower than SL after running but progressively increased throughout the 5-km run, (b) SF after cycling was higher than SF after running during the first half of the 5-km run but progressively decreased, (c) mean speed was not significantly different between the two conditions, and (d) efficiency after cycling increased above efficiency after running at the conclusion of the 5-km run. Thus, by the end of the 5-km run at race effort, the participants ran with the same average speed, but with altered step lengths and step frequencies and increased efficiency.

It is conceivable that the central nervous system, physiological limitations, and psychological perceptions influence performance during an event that involves cycling and running consecutively. Perseveration, the central pattern generator, motor programs, potentiation, and fatigue perhaps contribute to the altered running stride after cycling.

Cycling and running depend on different neural firing rates because of the specific cyclic frequencies of each activity. The neural firing rates for cycling during the cycle/run condition may not have immediately adapted to the new firing rate for running during the 5-km run (10). The coordinated neural control during cycling may have impaired the generation of an optimal running frequency, which would have resulted in perseveration (4), i.e., an involuntary, inappropriate maintenance of a prior activity.

Another feasible explanation at the neural level may include the abstract central pattern generator (CPG), which is an autonomous network of neurons at the spinal level (14). The CPG possibly dictates the frequencies involved for the activities in this study, cycling and running. This structure in the central nervous system determines the order of muscular contractions, the relative force of contractions, and the relative timing of the contractions, thereby coordinating various rhythmic movements (15). Thus, the firing rate of the CPG gradually transforms from the optimal cycling frequency to the optimal running frequency.

In addition, cycling and running probably demand an individual motor program, because the 2 activities require different sequencing and timing cues. If this is correct, then when the participants started to run, the cyclic frequency of the legs did not change until the new feedback signal initiated the motor program for running (15).

Potentiation is an increased amount of force generated by a consistent stimulus during a period of brief activity to the recruited muscles (6, 9). During the activity of running, the consistent stimulus is the force generated at the toe-off portion of each running stride, and the increased amount of force is demonstrated by the increased SL. Vandervoort, Quinlan, and McComas suggested that the increased force occurs after 8–10 minutes of constant stimulation (16). During the cycle/run condition, the participants possibly experienced potentiation during the 5-km run at race effort, whereas during the run/run condition, the participants possibly experienced potentiation during the initial running bout.

In the run/run condition, the participants experienced fatigue as indicated by the decrease in SL, accompanied by an increased HR and increased RPE, possibly because of a decrease in the force-generating ability of the muscle (11). The causes of fatigue and the loss of force output from the muscle are likely a result of a failure in the central nervous system or glycogen depletion (7, 8). In the cycle/run condition, the participants did not show these specific signs of fatigue, perhaps because of potentiation and the variation of muscle recruitment.

Summary

In conclusion, the results of the present study provide evidence that a cycling bout prior to a 5-km run at race effort initiated perseveration, which decreased the initial SL and increased the initial SF. As the 5-km run at race effort progressed during the cycle/run condition, the participants may have experienced potentiation, resulting in an increased SL and a decreased SF. By the end of the 5-km run at race effort, efficiency was significantly higher during the cycle/run condition than during the run/run condition, after the CPG or motor program transformed the optimal cycling cadence to the optimal running cadence without the detrimental effects of fatigue.

Practical Applications

Multisport athletes, who compete in events that involve cycling and running consecutively, can use this information. Training specifically for the effects presented here might combat these negative perceptions after the transition. For instance, once or twice a week, athletes could imitate a race situation by running at least 1 mile immediately after a cycling bout. These cycle/run sessions would aid the athletes in transitions without reducing the effect of the elevated efficiency demonstrated during the cycle/run condition. In addition, if the athletes experience perseveration because of a delayed transformation of the CPG or motor program, perhaps cadence during the cycling portion (95–100 revolutions$\cdot$min^{-1}) of a competition can be altered to mimic cadence during the following running portion (80–85 steps$\cdot$min^{-1}).

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