Running Stride Length And Rate Are Changed And Mechanical Efficiency Is Preserved After Cycling In Middle-Level Triathletes

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Although cycling impairs the subsequent metabolic cost and performance of running in some triathletes, the consequences on mechanical efficiency (Eff) and kinetic and potential energy fluctuations of the body center of mass are still unknown. The aim of this study was to investigate the effects of previous cycling on the cost-of-transport, Eff, mechanical energy fluctuations (Wtot), spring stiffness (Kleg and Kvert) and spatiotemporal parameters. Fourteen middle-level triathletes (mean ± SD: maximal oxygen uptake, VO2max = 65.3 ± 2.7 ml.kg⁻¹.min⁻¹, age = 30 ± 5 years, practice time = 6.8 ± 3.0 years) performed four tests. Two maximal oxygen uptake tests on a cycle ergometer and treadmill, and two submaximal 20-minute running tests (14 km.h⁻¹) with (prior-cycling) and without (control) a previous submaximal 30-minute cycling test. No differences were observed between the control and post-cycling groups in Eff or Wtot. The Eff remains unchanged between conditions. On the other hand, the Kvert (20.2 vs 24.4 kN.m⁻¹) and Kleg (7.1 vs 8.2 kN.m⁻¹, p < 0.05) were lower and the cost-of-transport was higher (p = 0.018, 3.71 vs 3.31 J.kg⁻¹.m⁻¹) when running was preceded by cycling. Significantly higher stride frequency (p < 0.05, 1.46 vs 1.43 Hz) and lower stride length (p < 0.05, 2.60 vs 2.65 m) were observed in the running after cycling condition in comparison with control condition.

Mechanical adjustments were needed to maintain the Eff, even resulting in an impaired metabolic cost after cycling performed at moderate intensity. These findings are compatible with the concept that specific adjustments in spatiotemporal parameters preserve the Eff when running is preceded by cycling in middle-level triathletes, though the cost-of-transport increased.

Mechanical efficiency (Eff) is defined as the ratio of total mechanical energy output to the total metabolic energy input and, therefore, integrates physiologic and biomechanical features 1–3. Furthermore, the total mechanical work (Wtot) represents the mechanical energy fluctuations from the body and segment center of mass, performed primarily by the muscles and tendons during running 1. Competitive distance runners may produce similar levels of external work with lower net energy expenditure and, thus, run at a higher Eff 5. Nonetheless, the effects of previous cycling on running Eff have not been verified in triathletes. The determination of Wtot and Eff, besides metabolic economy may be useful to understand the role of running technique on running performance.

Running cost-of-transport (CoT) is defined as the energy amount to cover a given distance commonly expressed in J.kg⁻¹.m⁻¹. It has been documented that CoT is one of the determinants of long-distance running performance 6–8. The CoT of triathletes is affected by cycling in a level-dependent manner. In elite triathletes, the CoT decreased by 3.7% and increased by 2.3% in middle-level triathletes 9. Two mechanisms were associated with to these findings: (i) a better metabolic economy of the respiratory muscles and, (ii) better stiffness regulation observed among the elite triathletes but not among their less successful counterparts 10–12.

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According to the spring–mass model system, the combination of passive (tendons and intramuscular connective tissues) and active (muscles) structures are responsible for elastic energy recovery during running\(^8\). The arch of the foot stores enough energy to make running more efficient and the metabolic energy saved by the arch is largely explained by the passive-elastic work it supplies that would otherwise be done by active muscle\(^11–13\), and, recently it was found that elastic bouncing was optimized in runners of the best performance level\(^14\). Although it is difficult to specify the extent to which the elastic mechanism affects the CoT and \(\text{Eff}\), higher \(W_{\text{tot}}\) and \(\text{Eff}\) are related to improvements in parameters of spring–mass model. It is possible to measure the parameters of this system through vertical stiffness (\(K_{\text{vert}}\)) and leg stiffness (\(K_{\text{leg}}\)), which allow an estimate of how compliant the system is with respect to, e.g., fatigue or prior exercise\(^15,16\). In middle and elite triathletes, no significant changes in \(K_{\text{leg}}\), \(K_{\text{vert}}\) stride length, and stride frequency were reported between the initial and final stages of an Olympic distance, specifically in triathletes who adopted the same running speed during these two stages\(^17\).

Hypothetically in a specific triathlon situation, the previous cycling could decrease the running \(W_{\text{tot}}\) worsening the running \(\text{Eff}\). Also, the decrease in the spring–mass stiffness after cycling would offer indirect evidence of the impairment of the running elastic mechanism. Consequently, there would be an increase in the metabolic component due to the decline in elastic energy return. The purpose of this study was to test the hypothesis that the augmentation in the CoT is related to changes in mechanical parameters (\(W_{\text{tot}}, K_{\text{leg}}\), and \(K_{\text{vert}}\)) and decrease in \(\text{Eff}\). The testing of these hypotheses may contribute towards a better design of training for triathletes.

Methods

Participants. Fourteen triathletes participated (average \(\pm\) SD: age = \(30 \pm 5\) years; body mass = 74.2 \(\pm\) 6.8 kg; stature = 179.1 \(\pm\) 7.3 cm; \(\text{VO}_{2\text{max}}\) = 65.3 \(\pm\) 2.7 ml kg\(^{-1}\) min\(^{-1}\); triathlon practice time \(>\) 6.8 \(\pm\) 3.0 years; weekly distance training (km) - cycling: 260 \(\pm\) 40; running: 43 \(\pm\) 9; swim: 11 \(\pm\) 3). These triathletes had regional level, defined, therefore, as middle level triathletes. The choice for these athletes was based on local availability. The inclusion criteria were: (i) having at least 2 years of experience in the triathlon, (ii) training for at least 12 h per week in the last year; and (iii) age \(>\) 18 years. The exclusion criterion included any orthopedic or musculoskeletal injury. The sample size was calculated using Winpepi software (version 4.0), in which a significance level of 0.05 and a power of 90% were adopted using the CoT, \(K_{\text{leg}}\), and \(K_{\text{vert}}\) variables\(^8,9,17,18\). The probability is 90 percent that the study will detect a treatment difference at a two-sided 0.05 significance level, if the true difference between conditions is 0.19 l kg\(^{-1}\) m\(^{-1}\) (smallest meaningful difference). All participants read and signed the informed consent form approved by the Ethics Committee of Federal University of Rio Grande do Sul (No. 579.277) before participating in the study. All experiments were performed in accordance with the Declaration of Helsinki.

Subjects performed four tests: two incremental tests (running and cycling) and two submaximal constant-speed running tests, both in random order (Fig. 1).

Maximal tests. The running and cycling maximal tests were performed to determine the maximal oxygen uptake (\(\text{VO}_{2\text{max}}\)) and confirm the metabolic intensity of subsequent submaximal tests. The subjects were prepared for the test by placement of a heart rate monitor Polar S810 (Polar Electro Oy, Kempele, Finland) and neoprene mask for gas collection. The heart rate, \(\text{VO}_2\), carbon dioxide (\(\text{VCO}_2\)), and ventilation per minute (\(\text{VE}\)) were continuously measured by indirect calorimetry throughout an automated gas analysis system (\(\text{VO}2000\), Medgraphics, St Paul, Minnesota, USA) validated accordingly\(^19\). The auto-calibration method of the system was executed daily before every test. Calibration of the calorimeter was carried out according to the manufacturer instructions. Every 5 days of data collection, a known gas mixture (5.01 CO\(_2\), 16.02 O\(_2\), balance N\(_2\)) was inserted into the system for simulation. In the running tests, subjects warmed up by walking on a treadmill for 6 minutes at 6 km h\(^{-1}\), and the initial load was 10 km h\(^{-1}\) with a 1% grade. The speed was increased by 1 km h\(^{-1}\) every 3 minutes until volitional exhaustion. In the cycling maximal tests, the initial load was 150 W 6 minutes and the subjects’ bikes were positioned on a cycle ergometer (Computrainer, ProLab 3D, Racermate Inc., Seattle, USA). After the warm up, the power output was increased by 25 W min\(^{-1}\) and cadence was maintained near 90 rpm and controlled by visual feedback until volitional exhaustion or until the subjects could not maintain the cadence of at least 70 rpm.

Submaximal tests. The gases were calibrated before every test. The ventilatory data were registered during whole test using the same automated gas analysis system utilized in the maximal tests. The tests started with the collection of \(\text{VO}_2\) and \(\text{VCO}_2\) in a standing position for six minutes. The warm up followed the same protocol...
described in the maximal tests. In the 'submaximal running after cycling' test, the athletes' bikes were fixed on a cycle ergometer and the athletes sustained a pedaling power of 10% below the ventilatory threshold for 30 minutes. The athletes were asked to make the transition from bike to run as fast as possible (<1 minute), and then perform the submaximal running test at 14 km.h^{-1} for 20 minutes. In all submaximal running tests the steady-state VO_2 was reached.

Concurrently with the collection of ventilatory parameters, kinematic data were recorded using a motion capture system (Vicon Motion Systems, United Kingdom) operating at 100 Hz. Six infrared Bonita and Tseries cameras registered the tridimensional positions of eighteen reflexive markers (14 mm diameter), fixed on the following anatomical landmarks: fifth metatarsal, calcaneus, lateral malleolus, femoral epicondyly, greater trochanter, acromion, lateral epicondyle of the humerus, middle point ulnar-radius, and temporal bone. Kinematic data were collected in one-minute durations four times, at the 3rd–5th, 8th–10th, 13th–14th, 18th–20th minute.

### Processing data. \( \dot{V}O_2 \text{max} \) and ventilatory threshold. \( \dot{V}O_2 \text{max} \) was determined as a plateau in \( VO_2 \) despite an increase in power output, a 1.15 respiratory exchange ratio, or an heart rate over 90% of the predicted maximal heart rate. The ventilatory threshold was determined as follows: i) a regular rise in the ventilatory equivalent of \( VO_2 \); ii) a concomitant nonlinear rise in the ventilatory equivalent of \( VO_2 \); and iii) a decrease in the difference in the inspired and end-tidal oxygen pressure. Two blinded experienced researchers located the ventilatory threshold by visual inspection.

Mechanical work (\( W_{int} \)), stiffness and spatiotemporal parameters. The body center of mass and location and body segment mass and locations were estimated. We calculated the mechanical energy fluctuations considering the external (\( W_{ext} \)) and internal (\( W_{int} \)) counterparts as proposed by Cavagna and Kaneko. The total external energy of the body center of mass is given as a function of time by the point-to-point sum of the gravitational potential and kinetic energies. The sum of positive increments from the total external energy curve results in the \( W_{ext} \). The mechanical energy fluctuations of the segments relative to the body center of mass were calculated. Additionally, the \( W_{int} \) was considered as the sum of the positive increments for each body segment separately, with an exception for arm plus upper arm and shank plus thigh, therefore, allowing intralimb energy transfer. The \( W_{tot} \) is calculated as \( |W_{ext}| + |W_{int}| \), and all mechanical energy variables are divided by body mass and stride length, hence, the unit is J.kg^{-1}m^{-1}. The mechanical power (\( P_{max} \)) was also calculated by dividing the \( W_{tot} \) by speed (in m.s^{-1}) and was expressed in W.kg^{-1}.

The stride length and frequency were determined by algorithms built in Nexus software. The maximal vertical force (\( F_{max} \)) from calculated the basis modelling of \( F(t) \) curves by a simple sinus function, vertical oscillation during contact (\( \Delta y_c \)), \( K_{vert} \) and \( K_{leg} \) were calculated according to estimations proposed by Morin and colleagues as follows:

\[
F_{max} = mg \left( \frac{L}{Tc} + 1 \right)
\]

where m is body mass, and g is gravitational acceleration. The \( \Delta y_c \) is determined as follows:

\[
\Delta y_c = \frac{F_{max} \cdot Tc^2}{m \pi^2} + g \cdot \frac{Tc^2}{8}
\]

Therefore, the \( K_{vert} \) is calculated as follows:

\[
K_{vert} = \frac{F_{max} \cdot \Delta y_c}{m \pi^2}
\]

Also, the stiffness of the leg spring (\( K_{leg} \) in kN.m^{-1}) was calculated as follows:

\[
K_{leg} = \frac{F_{max} \cdot \Delta L^{-1}}{m}
\]

where \( \Delta L \) is the maximum leg spring compression (in m) calculated from values of initial leg length L (great trochanter to ground distance in a standing position), running velocity (\( v \), in m.s^{-1}), contact time (\( Tc \), in s), and vertical maximal downward displacement of the body center of mass during contact \( \Delta y_c \):

\[
\Delta L = L - \sqrt{L^2 - \left( \frac{v \cdot Tc^2}{2} \right)} + \Delta y_c
\]

Cost-of-transport (CoT) and mechanical efficiency (Eff). The \( VO_2 \) of exercise was averaged from the 60 seconds at each stage (3rd–5th, 8th–10th, 13th–14th, 18th–20th minute) and was subtracted from \( VO_2 \) at rest. The running economy was denoted by CoT, expressed in J.kg^{-1}m^{-1}. We divided the net metabolic rate (gross − stand metabolic) rate by speed, and we converted oxygen in ml to Joules relative to combustion enthalpy of substrates resulting from oxidation observed indirectly from the respiratory exchange ratio. The metabolic power (Pmet) was also calculated and expressed in W.kg^{-1}. Eff is defined as the fraction of the CoT that is transformed into \( W_{tot} \), algebraically defined as \( Eff = W_{tot}/CoT^{-1} \). All data can be seen in the electronic Supplementary Material (ESM 1).

### Statistical analysis. Descriptive statistics were analyzed with mean and standard deviation. The specific tests below were used to compare the dependent variables between running-after-cycling versus just-running
conditions at four stages throughout the submaximal running tests. Shapiro-Wilk’s and Levene’s tests confirmed the normality and the homogeneity of the variances, respectively. A paired t-test was used to compare the means of the dependent variables with and without previous cycling, and a one-way ANOVA was used to compare the dependent variables at different stages of submaximal tests with a Bonferroni post hoc test to locate the differences. The significance level adopted was \( \alpha = 0.05 \) and all data were processed in the SPSS version 17.0 statistical package.

**Results**

Figure 2 shows the CoT data. CoT was increased with previous cycling and was kept constant during the four stages of submaximal running tests. Therefore, the triathletes performed the submaximal tests running in a moderate metabolic domain (corresponding to approximately 72% \( \dot{V}O_{2\text{max}} \) and 82% ventilatory threshold).

No significant differences were found in \( W_{\text{int}} \) (\( p > 0.05 \)) between running with or without previous cycling, nor with the time factor (Fig. 3). The running \( W_{\text{int}} \) values on average were 0.59 J.kg\(^{-1}\).m\(^{-1}\) with previous cycling and 0.57 J.kg\(^{-1}\).m\(^{-1}\) without previous cycling. The \( W_{\text{ext}} \) values also remained unchanged between running with and without previous cycling (\( p > 0.05 \)). However, \( W_{\text{ext}} \) and \( W_{\text{tot}} \) were lower at the final stage compared to those at the second and third stages (\( p < 0.05 \)) only for running without previous cycling (\( p < 0.05 \)). The \( P_{\text{met}} \) and \( P_{\text{mec}} \) values are listed in the electronic Supplementary Material (ESM 2).

The \( \text{Eff} \) remained unchanged along the test independently of conditions. Also, the previous cycling was not capable of promoting changes in the \( \text{Eff} \) in comparison with control condition (\( p > 0.05 \), Fig. 4).
The light gray and dark gray bars represent the mean and standard deviation of Eff in Post-cycling run and control run, respectively. *Represents p < 0.05 of the paired t-test.

Spring-mass and spatiotemporal parameters. The stride length and frequency, Kleg and Kvert, did not change across all sections of the tests (p > 0.05; Table 1). However, the triathletes decreased their Kleg and Kvert at the end of the test between running after cycling and running without previous cycling. They increased their cadence and reduced their stride length systematically when they ran with previous cycling in comparison to the control condition. While the contact and flight times were similar between conditions in the first three sections, in the last section the contact time was higher and the flight time was lower in the previous cycling condition than those in the control condition. In addition, higher Fmax and smaller ΔL and Δyc values were found in the last section in the previous cycling condition compared to the control condition.

Discussion
The purpose of this study was to test the hypothesis that the running CoT would increase when preceded by cycling exercise associated with decreases in Wtot, Kleg, and Kvert, resulting in reduction in Eff. The hypothesis was refuted because the Eff remains unchanged after cycling in middle-level triathletes, although there was increase in CoT, adding that this decreasing of metabolic economy was related to mechanical adjustments. That is, middle-level triathletes systematically reduce their stride length and increase their stride frequency when running after cycling, in comparison to running without previous cycling, preserving mechanical efficiency and work. Therefore, the findings of similar Kleg and Kvert are partly in line with a previous study8, which reported that elite triathletes preserved their neuromuscular control and running economy after cycling. Also, the maintenance of stiffness observed in our study, confirms previous rationale showing that a better stiffness regulation in the elite triathletes but not in their less successful counterparts5.

In these studies, however, the protocols vary greatly, and the reports are level-dependent. For example, in other studies comparing physiological parameters and performance after two previous cycling protocols in well-trained athletes, one protocol with constant intensity and another with variable intensity, the triathletes showed greater physiological deterioration in the race following the test with variable intensity of cycling34. The protocol of the present study kept the intensity of cycling constant with cycling power equivalent to 80% of the ventilatory threshold. It is important to consider the distance of the triathlon competition and the repercussions of these distances on adopted pacing strategies during specific disciplines within the triathlon35.

Our findings show that the inclusion of cycling prior to running preserved Eff at the end of the submaximal running test (Fig. 3). Eff is determined as the ratio between the Wtot and CoT, and the reduction in Eff in the control condition (without previous cycling) was mainly explained by the decrease in total mechanical work, consequently due to reduced Wtot during the final section of the test (Fig. 1). In a previous study, middle-level triathletes showed no difference in Wtot with and without previous cycling, but the running protocol was seven minutes long and the mechanical and metabolic parameters were collected only once during each running test5. The reasons for better metabolic economy in high level and lower metabolic economy in middle level triathletes found in previous studies are yet to be solved. Our study shows that, in middle level triathletes, the metabolic economy is deteriorated in association to lower stride length. Thus, our results are in line with previous studies analyzing short-duration tests but showed differences when evaluated over a longer time. In the present study, the running time was relatively long and the intensity was approximately 70% ventilatory threshold. The Wtot during the race with previous cycling is the main explanation for the better Eff in the final section because, in the present study, the CoT remained constant during all stages. Again, in the final section, the Wtot was higher during the race with previous cycling. Candau et al.34 found an increase in Wtot and O2 consumption from the beginning to the end of the running test at a high-intensity constant speed until exhaustion in triathletes. Avogadro et al. (2003), also using a constant velocity protocol until exhaustion in runners and triathletes, found an increase in O2 consumption at the end of the test, but with no change in mechanical cost. The slow component of VO2 in progressive race velocity was previously investigated and it was demonstrated that the slow component of VO2 was not a result of changes in the production of mechanical work35. However, in these studies, the metabolic intensity was higher and the exercise duration was shorter than in our study.
Stiffness at the end of the running test was lower with previous cycling in comparison to control conditions. This mechanical alteration may have helped to maintain the Eff, demonstrating a positive adaptation factor of triathletes to previous cycling. Borrani et al. suggested that the slow component of VO\(_2\) during running may be due to changes in the storage and reuse of elastic energy. Studies that evaluated races over a longer period, for example, 5 h38 and 24 h39 races, found an increase in K\(_{leg}\) and K\(_{vert}\) at the end of the races, and these changes may be interpreted as a smoother technique with a decrease in the vertical oscillation of the mass-spring system. In addition, the stiffness of the mass-spring system has a negative correlation with running CoT and the athlete was more economical due to running mechanics.

Training specificity is an important factor to determine athlete performance. Triathletes who train sequentially in the three modalities have specific mechanical and metabolic adaptations in contrast to athletes who train, for example, running in isolation. The responses in the running CoT after pedaling are highly controversial. Some findings indicate lower values and others indicate similar values in high-level triathletes. Even higher values of CoT have been found in lower-level triathletes.

Table 1. The mechanical parameters are presented as mean ± SD in the four sections of submaximal running tests following control and post-cycling run. *Significantly different from previous cycling condition, p < 0.05. Note: SL – stride length; SF – stride frequency; T\(_c\) – contact time; T\(_f\) – flight time; K\(_{leg}\) – leg stiffness; K\(_{vert}\) – vertical stiffness; F\(_{max}\) – maximal force; ΔY\(_c\) – vertical oscillation during the contact; ΔL – vertical oscillation during the step.

| Time (min) | Y’–5’ | 5’–10’ | 10’–15’ | 15’–20’ | 15’–25’ | 25’–30’ |
|-----------|-------|--------|--------|--------|--------|--------|
| SL (m)    | 2.59 ± 0.10 | 2.59 ± 0.10 | 2.64 ± 0.11 | 2.60 ± 0.10 | 2.61 ± 0.11 | 2.65 ± 0.12 |
| SF (Hz)   | 1.46 ± 0.06 | 1.46 ± 0.06 | 1.45 ± 0.06 | 1.43 ± 0.06 | 1.45 ± 0.05 | 1.43 ± 0.06 |
| T\(_c\) (s) | 0.253 ± 0.026 | 0.255 ± 0.030 | 0.254 ± 0.026 | 0.250 ± 0.020 | 0.247 ± 0.026 | 0.245 ± 0.021 |
| T\(_f\) (s) | 0.092 ± 0.017 | 0.093 ± 0.021 | 0.097 ± 0.013 | 0.093 ± 0.012 | 0.099 ± 0.015 | 0.088 ± 0.018 |
| K\(_{leg}\) (kN.m\(^{-1}\)) | 7.57 ± 1.42 | 7.51 ± 1.42 | 7.65 ± 1.60 | 7.25 ± 1.27 | 7.62 ± 1.23 | 7.98 ± 1.23 |
| K\(_{vert}\) (kN.m\(^{-1}\)) | 21.77 ± 3.27 | 21.77 ± 3.77 | 21.41 ± 3.59 | 21.96 ± 3.94 | 21.95 ± 2.87 | 22.09 ± 1.98 |
| F\(_{max}\) (N) | 1597 ± 149 | 1585 ± 163 | 1612 ± 145 | 1609 ± 150 | 1602 ± 78 | 1650 ± 125 |
| ΔY\(_c\) (m) | 0.215 ± 0.035 | 0.223 ± 0.037 | 0.210 ± 0.029 | 0.213 ± 0.035 | 0.215 ± 0.030 | 0.210 ± 0.040 |
| ΔL (m) | 0.080 ± 0.010 | 0.079 ± 0.013 | 0.081 ± 0.013 | 0.081 ± 0.012 | 0.083 ± 0.007 | 0.076 ± 0.008 |

Stride length and frequency presented an inverse relationship, with a short length and a high frequency when prerace cycling was performed. Although, changes in CoT have been observed between races with and without prior cycling, the Eff was preserved, demonstrating that athletes altered their mechanics to optimize their CoT, since runners naturally opt for a combination of stride frequency and stride length to minimize metabolic cost. This mechanism has been recently shown by Lussiana et al. where the strategy of energy minimization is limiting the vertical oscillation of body center of mass to promote forward progression throughout a low duty factor (relatively long time contact and short flight time) resulting in a running technique less bouncy. In addition, the increased stride frequency and reduced stride length seem to reduce the magnitude of the biomechanical factors associated with running injuries and, therefore, this mechanical alteration seems also to occur as a protective factor for triathletes. The F\(_{max}\), ΔL, and ΔY\(_c\) during the previous cycling test presented lower values at the end compared to the isolated run, as found by Morin et al. after a long run (24 h), corroborating with the hypothesis of a change in mechanics for Eff maintenance and mechanical work after the moderate intensity cycling protocol. Another interpretation, from an integrative point-of-view, is that the maintenance of mechanical work and Eff accompanied by an increase in CoT provides a clear evidence that the muscle efficiency, in turn, could be interpreted as a smoother technique with a decrease in the vertical oscillation of the mass-spring system. The slow component of VO\(_2\) during running may be due to changes in the storage and reuse of elastic energy. Studies that evaluated races over a longer period, for example, 5 h38 and 24 h39 races, found an increase in K\(_{leg}\) and K\(_{vert}\) at the end of the races, and these changes may be interpreted as a smoother technique with a decrease in the vertical oscillation of the mass-spring system. In addition, the stiffness of the mass-spring system has a negative correlation with running CoT and the athlete was more economical due to running mechanics.

An important limitation of the study is that the constant velocity protocol adopted in the submaximal test has less ecological validity when compared to field tests. However, the laboratory tests are able to isolate factors that would alter the variables as a function of speed variation that modifies the biomechanical and physiological components. In a study comparing the behavior of the mass-spring system in four stages at ≈2,400 m − 4,800 m − 7,200 m − 9,600 m during a 10 km triathlon race, K\(_{leg}\) and K\(_{vert}\) variables decreased from the 1st to 3rd stages and increased in the 4th stage. This finding is related to the change in velocity that occurred during the test. Keeping the speed constant, within a controlled intensity range, we were able to isolate this factor and observe that previous cycling also influences the stiffness of the mass-spring system.
Conclusion
Pre-race cycling increase the running CoT in middle-level triathletes. The mechanical work and stiffness of the spring-mass system are maintained throughout a constant speed test when cycling at moderate intensity, demonstrating that pre-race cycling can contribute to the maintenance of mechanical efficiency in triathletes. In addition, the stride length decreases and the stride frequency increases with previous cycling, demonstrating an adaptation of the technique for Eff maintenance.

Received: 27 June 2019; Accepted: 18 November 2019;
Published online: 05 December 2019

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Acknowledgements

We are grateful to the Locomotion Group of the Universidade Federal do Rio Grande do Sul for discussions and comments. We extend our acknowledgements to all Brazilian citizens who, through the payment of their taxes, allow so many researchers to improve their scientific knowledge in public graduate programs.

Author contributions

R.G.R and L.A.P.T. conceived of the study and designed the experiments. L.A.P.T. obtained the funding. R.G.R, H.B.O., N.A.G., G.F. and L.A.P.T. carried out the analysis, interpreted the statistical results, and drafted the manuscript. R.G.R., H.B.O., N.A.G., collected the data. R.G.R., H.B.O., N.A.G., L.P.A., G.F. and L.A.P.T. contributed to the manuscript to the formal analysis, writing, read, and approved the final manuscript.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information is available for this paper at https://doi.org/10.1038/s41598-019-54912-6. Correspondence and requests for materials should be addressed to L.A.P.-T.

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