Cocontraction and economy of triathletes and cyclists at different cadences during cycling motion

Cláudia Tarragô Candotti b,*, Jefferson Fagundes Loss a, Daniel Bagatini a, Denise Paschoal Soares a, Everton Kruel da Rocha a, Álvaro Reischak de Oliveira a, Antônio Carlos Stringuini Guimarães a

a School of Physical Education, Federal University of Rio Grande do Sul, Porto Alegre, Brazil
b School of Physical Education, University of Vale do Rio dos Sinos, São Leopoldo, Brazil

Received 5 October 2006; received in revised form 28 February 2008; accepted 10 April 2008

Abstract

The purpose of this study was to compare the cycling technique of triathletes and cyclists on the basis of the cocontraction of selected muscles of the lower limbs and economy at different cadences. The economy (EC) and percent cocontraction from nine triathletes and eight cyclists were compared at 60, 75, 90 and 105 rpm cadences. Tests were performed on two separate days. The maximal oxygen uptake was measured and the second ventilatory threshold (VO$_2$VT) was estimated on the first day using a stationary bicycle. On the second day the four different cadences were tested at approximately 5% below the VO$_2$VT. The EMG activity of the rectus femoris (RF), biceps femoris (BF) and vastus lateralis (VL) was recorded and the EMG signal was normalized using the 60 rpm dynamic contraction. The percent cocontractions were calculated from RF/BF and VL/BF muscles. The EC was also calculated. The results showed that cyclists were significantly more economic, indicating that they exerted more power with less VO$_2$, and presented significantly lower percent cocontraction than triathletes ($p<0.05$). Thus, the results suggest that the cyclists had a better technique than the triathletes. The simultaneous use of the percent cocontraction and economy seems to be a good performance indicator for cyclists and triathletes.

© 2008 Elsevier Ltd. All rights reserved.

Keywords: Cycling; Triathlon; EMG; Economy; Cocontraction

1. Introduction

The interesting and complex interaction between a rider and a bicycle has made cycling attractive to scientists. In some investigations the focus is the cycling technique itself, and the goal is to produce relevant information for coaches and athletes (Sanderson and Cavanagh, 1990), by measuring electromyographic activity (EMG) of the muscles of lower limbs (Hautier et al., 2000; Sarre et al., 2003; Lucia et al., 2004; Sarre and Lepers, 2005). Analysis of pedaling technique with EMG can be performed using cocontraction indexes (Hautier et al., 2000), since cocontraction can be interpreted as a pattern of inefficiency in a dimension in which antagonist muscles fight against each other to produce a net movement (Winter, 2005). In a study involving cycling activity in which children with typical development were compared with children with cerebral palsy, the latter had increased cocontraction (Johnston et al., 2007). The authors go on to discuss the relative efficiency of this pattern in cycling.

Recent studies have investigated the effect of cadence on EMG and economy during cycling (Lucia et al., 2004), suggesting an increase in EMG activity and decrease in economy at slow cadences compared with higher pedaling rates. From a physiological point of view the economy can be understood as a quotient between
power output and corresponding oxygen uptake (Moseley and Jeukendrup, 2001). The increased viscous resistance to motion of contracting muscle filaments associated with the speed of contraction (Elliott and Worthington, 2001) together with the failure of a muscle to relax between contractions could potentially contribute to an increased metabolic cost of cycling (McDaniel et al., 2002), affecting the cycling economy.

Considering that, in competitive cycling, performance is highly dependent on how economic the athletes are, it is not surprising that in some investigations the authors have attempted to associate biomechanical variables with economy (Marsh and Martin, 1995; Gotshall et al., 1996; Marsh and Martin, 1997; Neptune and Herzog, 1999; Brisswalter et al., 2000). Taking into account that economy seems to be affected by the technique employed by athletes it is reasonable to speculate that expert cyclists, who have good technique, will also be economical.

The literature contains EMG patterns obtained from recreational riders as well as from international level athletes, but interestingly there is little information on triathletes (Neptune et al., 1997; Li and Caldwell, 1998; Baum and Li, 2003). If the cycling technique is important for the performance of cyclists, it should be at least as important for triathletes. Triathlon has recently been introduced into the Olympic Games, and although cycling is only one of three activities that triathletes need to perform, it takes most of the total time of the race and it precedes running, an activity that also predominantly demands use of the lower limbs. Besides, the running in triathlon has an oxygen cost 7–8% higher than isolated running (Hausswirth et al., 1997; Hausswirth et al., 1999). So, during a triathlon race there is a decrease in economy (Hausswirth et al., 1996), and the success of triathletes depends on how economic they are (Miura et al., 1997). Therefore, it is important for triathletes to have a good cycling technique since it may also affect their running. Given that cyclists are entirely devoted to cycling whereas triathletes need to practice two other activities, it seems interesting to compare the cycling technique of the two different types of athletes, assuming the technique of cyclists to be the gold standard. The purpose of this study was to compare the cycling technique of triathletes and cyclists on the basis of cocontraction of selected muscles of the lower limbs and economy at different cadences.

2. Methods

2.1. Subjects

Nine cyclists and eight triathletes were analyzed. This study was approved by the university ethics committee, and the subjects signed a written consent form. All athletes were involved in competitions that lasted at least 2 h and participated in state and national events. Information regarding age, years of practice and physical characteristics is shown in Table 1.

<table>
<thead>
<tr>
<th>Characteristics of the athletes: mean (±standard error)</th>
<th>Age (yrs)</th>
<th>Time of practice (yrs)</th>
<th>Mass (kg)</th>
<th>Height (m)</th>
<th>Body fat (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyclists</td>
<td>25.1 ± 1.0</td>
<td>7.7 ± 0.8</td>
<td>67.1 ± 0.7</td>
<td>1.73 ± 0.01</td>
<td>8.9 ± 0.2</td>
</tr>
<tr>
<td>Triathletes</td>
<td>27.5 ± 1.0</td>
<td>6.9 ± 0.5</td>
<td>68.1 ± 1.0</td>
<td>1.73 ± 0.01</td>
<td>8.1 ± 0.2</td>
</tr>
</tbody>
</table>

2.2. Data acquisition

The evaluation of the athletes was performed on two separate days when acquisition of VO2, EMG of three muscles and video recordings were performed.

2.2.1. First day testing

The subjects performed a cycle ramp test using an ergometer (Cardio2 bicycle, Medical Graphics Corp. St. Louis, USA) adapted with competitive clipless pedals, handlebars and saddle. The initial warm-up power of 30 W was maintained for 3 min, and the power was then increased at 30 W min⁻¹, until exhaustion. The subjects were allowed to adopt their preferred cadence.

Ventilatory data were recorded during of the ramp test using a breath-by-breath automated metabolic system (CPX/D Medical Graphics, Corp. St. Louis, USA): minute ventilation (VE), VO2, carbon dioxide production (VCO2), respiratory exchange ratio (RER), ventilatory equivalent for oxygen (VE/VO2), ventilatory equivalent for carbon dioxide (VE/VCO2), breathing frequency (f), and tidal volume (V).

Two criteria were used to determine that the athletes had reached their VO2max: (1) a constant leveling off of VO2 despite an increase in exercise intensity and (2) RER greater than 1.10. The second ventilatory threshold (VO2VT) was determined using the criterion of increase in VE/VO2 and VE/VCO2, with a concomitant decrease in end tidal pressure (Ribeiro et al., 1986).

In contrast to previous studies that have established fixed loads for different subjects (Marsh and Martin, 1995; Sarre et al., 2003), in this investigation the load at which each subject was evaluated on the second day test was defined by their individual VO2VT. In other words, a physiological normalization criterion was used in an attempt to ensure that different individuals worked at a similar metabolic rate (Candotti et al., 2007).

2.2.2. Second day testing

Four different cadences (60, 75, 90 and 105 rpm) were randomly assigned to each participant. During the test VO2 was continuously monitored in order to keep it at approximately 5% below the VO2VT. Thus, it was necessary to individually adjust the load to keep the VO2 close to the desired level until each athlete reached their own steady state (Coyle et al., 1991). Approximately 5 min was needed to reach VO2 (steady state), after which, no changes in the load was necessary and each trial was performed for a further 3 min. The EMG data was collected during the last 30 s of this period.

The EMG activity of the rectus femoris (RF), biceps femoris (BF) and vastus lateralis (VL) was recorded from the right lower limb of the subjects, in accordance with “Standards for reporting EMG data” (Electromyography and Kinesiology, 1997). These thigh muscles were selected because they are major contributors
to cycling during the propulsive phase (Jorge and Hull, 1986; Ericson, 1988; Raasch and Zajac, 1999). The preparation for surface EMG detection included shaving and alcohol applied to cleansed skin. Disposable surface electrodes (Ag/AgCl; 1.0 cm diameter) were placed in a bipolar configuration (2.5 cm apart, center to center) on the bellies of the muscles, observing the supposed alignment of the muscle fibers. A single reference electrode was placed on the right tibia of the subjects.

The recordings were made with the aid of an eight-channel EMG system (Bortec Electronics Inc., Calgary, Canada) comprised of pre-amplifiers (fixed gain of 500) which were located approximately 10 cm away from the electrodes. The input impedance of the system was 10 GOhms; band-pass between 10 and 1000 Hz at −6 db; the common mode rejection rate (CMRR) was 115 db (at 60 Hz) and the signal to noise ratio was 4.5 μ volts RMS (10 Hz–3 kHz). The system was connected to a personal computer Pentium 200 MHz using a 16-channel, 12 bits AD board (Dataq Instruments Inc., Akron, USA). The sampling frequency was set at 20,000 Hz, for eleven channels (1818 Hz for each channel).

The angular motion of the pedal and crank were simultaneously recorded using a 2D video system (Peak Performance Technologies Inc., Englewood, USA) operating at 120 Hz. Reflexive markers were set on the pedal and crank so that their respective angles could be determined throughout the 360° of the crank revolution. The video and EMG systems were synchronized so that all variables could be expressed as a function of pedal angle or crank angle. The synchronization was achieved by means an electronic system in which a light flashed in a video camera and at the same time a voltage signal was sent to a dedicated AD board channel.

2.3. Data processing and analysis

2.3.1. Economy

Mean VO\(_2\) and power output were computed during the last 30 seconds of each trial. The economy was calculated according to Eq. (1) (Moseley and Jeukendrup, 2001)

\[
EC = \frac{P}{V_{O2}} \quad (1)
\]

where EC is the economy (kJ l\(^{-1}\)), P the mean power recorded during steady state (W) and \(V_{O2}\) is the corresponding mean oxygen uptake (1 min\(^{-1}\)).

2.3.2. EMG

The average EMG signal was calculated using the first 10 consecutive cycles of pedaling from the 30 s of recording data. EMG data processing was performed using self developed software SAD32 [version 2.61.07, www.ufrgs.br/lmm]. Raw EMG was initially submitted to a band-pass filter (Butterworth, 5th order, 20–600 Hz), following which the EMG signal was smoothed by moving window average process root mean square (RMS) using 40 ms of Hamming windows (Neptune et al., 1997). Normalization of the EMG signal from each subject was calculated using the maximum value obtained from among the ten consecutive cycles when subjects were pedaling at 60 rpm (Lucia et al., 2004). Following this process, the normalized mean curve from the consecutive ten cycles was calculated and expressed as a function of crank angle, for each cadence.

The percent cocontraction between the rectus femoris and biceps femoris muscles was calculated according to Eq. (2) (Winter, 2005). The cocontraction between vastus lateralis and biceps femoris muscles was also calculated

\[
%COCON = 2 \times \frac{\text{common area } A&B}{\text{area } A + \text{area } B} \times 100\% \quad (2)
\]

where % COCON is the percent cocontraction between two antagonist muscles, area A the area below the EMG smoothed curve of muscle A, area B the area below the EMG smoothed curve of muscle B, common area A & B is the common area of activity between two antagonist muscles.

2.4. Statistical analysis

The data are reported as mean ± SE (standard error). The variables obtained on the first day (\(VO_{2\text{max}}, VO_{2VT}\) and load) and the characteristics of the athletes (age, time of practice, mass, height and body fat) were analyzed using an independent-sample \(t\)-test. In order to analyze the variables obtained on the second day (EC, \(VO_{2VT}\), \%COCON between RF–BF and \%COCON between VL–BF) a casual block design was adopted for each dependent variable: two groups (cyclists and triathletes) and four cadences (60, 75, 90 and 105 rpm). The equality of the error variance in the data of was confirmed using Levene’s test and data normality was confirmed using the Shapiro–Wilk test. The second-day variables were submitted to multiple one-way ANOVAs and in the case of significant differences they were further submitted to a Tukey post hoc test. The level of significance adopted was 0.05 and all statistical procedures were performed using the SPSS version 10.0 software.

3. Results

The mean cadences adopted by cyclists and triathletes were 105 ± 5 rpm and 90 ± 3 rpm, respectively, during the first day. The \(VO_{2\text{max}}, VO_{2VT}\) and the corresponding load of cyclists and triathletes obtained during the first day of testing are presented in Table 2 along with the \(VO_{2VT}\) at each cadence obtained during the second day of testing. A significant difference was found between the \(VO_{2\text{max}}\) of cyclists and triathletes but not between their respective \(VO_{2VT}\). All athletes were able to perform each task in the load corresponding at calculated \(VO_{2VT}\).

When the EC from each of the two groups were compared, cyclists were significantly more economic than triathletes at all cadences (Table 3). When the different cadence rates were taken into consideration within the EC no significant differences were found, either for cyclists or for triathletes.

The mean and standard error of the percent cocontraction between the rectus femoris and the biceps femoris muscles are shown in Table 4. When the cocontractions from each of the two groups were compared, cyclists presented a significantly lower percent cocontraction than triathletes at 60, 75 and 90 rpm, but not at 105 rpm. Table 5 shows the mean and standard error of the percent cocontraction between vastus lateralis and biceps femoris muscles. Cyclists presented significantly lower percent cocontraction than triathletes at all cadences. When the different cadence rates were taken into consideration within the cocontraction (between RF–BF and between VL–BF) no significant differences were found, either for cyclists or for triathletes.
Fig. 1 shows the mean processed EMG corresponding to the 90 rpm cadence of the three studied muscles for all cyclists and triathletes. While cyclists and triathletes showed similar muscle activation patterns for the vastus lateralis and rectus femoris muscles, a distinct activation strategy was seen in the biceps femoris muscle. This difference could have produced the aforementioned results for the cocontraction index.

4. Discussion

The purpose of this study was to compare the cycling technique of triathletes and cyclists on the basis of EMG activity of selected muscles of the lower limbs and EC at different cadences. Considering that the level of effort kept in all trials was normalized using the VO$_{2VT}$, the two groups of athletes performed at a similar physiological level, and can, therefore, be compared in terms of their technique. The main results show that cyclists are more economical than triathletes, in all cadences (Table 3), and when muscle activity was compared, cyclists were seen to have a lower percent cocontraction than triathletes (Tables 4 and 5).

The results obtained from the two groups of athletes, from a qualitative point of view, are in accordance with the data available on the literature (Gregor et al., 1981; Pons and Vaughan, 1989; Marsh and Martin, 1995; Neptune et al., 1997; Raasch et al., 1997; Neptune and Herzog, 2000; Gregor, 2000; Zajac, 2002; Baum and Li, 2003). Though the athletes in the present study were not of an international level, a reasonable resemblance was found in the general aspect of the cyclists’ a curves when compared with those of the aforementioned studies. Therefore, we consider that, though dealing with athletes of national level, the results found can be used as reference for comparison with data of triathletes, which were less economical and, therefore, possibly less technical.

Observing Fig. 1, there is a notable reasonable resemblance between the activation patterns of the rectus femoris and vastus lateralis when we compared cyclists and the triathletes. However, the strategy adopted by cyclists seems to activate the biceps femoris at the end of quadrant 1 [from 0 to 90], until quadrant 3. The triathletes, on the other hand, keep this muscle activated in quadrant 1 and 2. This strategy may be associated to the need of the triathlete to use that same musculature during the next stage of the competition. This distinct activation pattern is related to the results obtained for the percent cocontraction.

The cyclists presented lower percent cocontraction between the rectus and biceps in three of the four cadences analyzed (Table 4) and in all cadences between the vastus and biceps (Table 5). This may be an indicator of better technique, considering cocontraction as a reflex of inefficient movement (Winter, 2005). Based on the principle of muscle adaptability it could be understood that the cyclist who trains exclusively pedaling exercise achieves a greater efficiency in the musculature involved. On the other hand, even without such a degree of specificity in training, the triathlete needs to practice the pedaling exercise considering the economy of movement, since following the cycling stage, great demand will be made on the lower limbs during

### Table 2
Mean and standard error of maximal oxygen uptake (VO$_{2\text{max}}$), second ventilatory oxygen uptake (VO$_{2VT}$) and corresponding load on first day of testing; and second ventilatory oxygen uptake (VO$_{2VT}$) at different cadences obtained during the second day of testing.

<table>
<thead>
<tr>
<th>First day</th>
<th>Second day</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO$_{2\text{max}}$ (l/min)</td>
<td>VO$_{2VT}$ (l/min)</td>
</tr>
<tr>
<td>Cyclists</td>
<td>Triathletes</td>
</tr>
<tr>
<td>4.0 (±0.2)</td>
<td>3.4 (±0.2)</td>
</tr>
<tr>
<td>3.2 (±0.1)</td>
<td>2.9 (±0.1)</td>
</tr>
<tr>
<td>272 (±21.4)</td>
<td>249 (±8.4)</td>
</tr>
<tr>
<td>3.2 (±0.1)</td>
<td>2.8 (±0.1)</td>
</tr>
</tbody>
</table>

* Significant difference ($\alpha < 0.05$) between cyclists and triathletes.

### Table 3
Mean and standard error of economy [kJ/l] for cyclists and triathletes at the four cadences.

<table>
<thead>
<tr>
<th>Cyclists</th>
<th>Triathletes</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 rpm</td>
<td>75 rpm</td>
</tr>
<tr>
<td>VO$_{2VT}$ (l/min)</td>
<td>VO$_{2VT}$ (l/min)</td>
</tr>
<tr>
<td>5.2 ± 0.7</td>
<td>4.8 ± 0.8</td>
</tr>
<tr>
<td>3.9 ± 0.4</td>
<td>3.9 ± 0.4</td>
</tr>
</tbody>
</table>

* Significant difference ($\alpha < 0.05$) between cyclists and triathletes.

### Table 4
Mean and standard error of the percent cocontraction between rectus femoris and biceps femoris at the four cadences.

<table>
<thead>
<tr>
<th>Cyclists</th>
<th>Triathletes</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 rpm</td>
<td>75 rpm</td>
</tr>
<tr>
<td>Percent cocontraction</td>
<td>Percent cocontraction</td>
</tr>
<tr>
<td>35.5 ± 1.3</td>
<td>35.3 ± 2.5</td>
</tr>
<tr>
<td>47.8 ± 5.2</td>
<td>49.0 ± 6.8</td>
</tr>
</tbody>
</table>

* Significant difference ($\alpha < 0.05$) between cyclists and triathletes.

### Table 5
Mean and standard error of the percent cocontraction between vastus lateralis and biceps femoris at the four cadences.

<table>
<thead>
<tr>
<th>Cyclists</th>
<th>Triathletes</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 rpm</td>
<td>75 rpm</td>
</tr>
<tr>
<td>Percent cocontraction</td>
<td>Percent cocontraction</td>
</tr>
<tr>
<td>44.6 ± 2.9</td>
<td>45.0 ± 1.1</td>
</tr>
<tr>
<td>63.4 ± 7.5</td>
<td>77.6 ± 3.2</td>
</tr>
</tbody>
</table>

* Significant difference ($\alpha < 0.05$) between cyclists and triathletes.
the running stage. A muscle pattern with a higher level of cocontraction suggest a less efficient activity. The results obtained in this study do not allow us to reach a definite conclusion. Nevertheless, it is possible to speculate that the fact of training three different modalities does not affect the pattern of muscle activity, though the specificity of the training programs used by cyclists appears to induce a more efficient muscle recruitment pattern. Both groups, cyclists and triathletes, trained for the same length of time, but the triathletes had higher rates of cocontraction, this would suggest that the specificity of the training appears to be more important than the volume in perfecting the executed task. It is important to bear in mind, however, that the cocontraction was only calculated for two sets of antagonists (RF–BF and VL–BF), which are considered important propellers in pedaling (Gregor, 2000). It is also important to point out that this cocontraction index, obtained from the electromyographical signal, indicates a situation in which there is “simultaneous activation” of the musculature, suggesting loss of efficiency in relation to an increase in the index. A cocontraction rate of 100% does not necessarily mean “there will be no movement”, but means that both analyzed muscles were simultaneously activated at the same relative intensity during the same length of time. Depending on the mechanical conditions involved in the situation such as, the moment arm of each of the analyzed muscles, it is possible to obtain a certain balance in the torques produced, or the effect may be greater in one or other direction.

Theoretically, the most economical situation would be that in which there were no cocontraction, since cocontraction can be reduced with training (Hautier et al., 2000). In other words, we hypothesize that cyclists probably have learned to better use their antagonist muscles to transfer force more efficiently. In the case that the EC influences the increase in muscle coordination and consequently the increase in mechanical efficiency (Viru and Viru, 2000) the results obtained in the present study for economy would be explained. Mechanical aspects in movement execution influence metabolic expenditure in such a way that differences in pedaling patterns influence the EC (Sleivert and Rowlands, 1996).

Assuming the EC is an expression of performance, since physiological and technique aspects are involved in pedaling, the results of the present study support the assumption that cyclists are more technical than triathletes. Hausswirth et al. (1997) have sustained that differences in cadence influence EC. While there are studies that indicate that slow cadences are more economic and efficient, considering the energy and technique, respectively (Takaishi et al., 1998), others show the opposite, slow cadences are less economic (Lucia et al., 2004). In the present study cadence did not
seem to significantly influence economy for the cyclists or triathletes. We could expect that athletes would present better EC in higher cadences, since they are preferred during training and competition. If we discard aerobic as determinant factor in the selecting cadence (Marsh and Martin, 1992) and consider minimization of neuromuscular fatigue to be determinants (Marsh et al., 2000; Brisswalter et al., 2000), it would then be interesting to analyze the pattern of muscular activation from a wider perspective, since that the EC reflects, ultimately, the muscular contraction necessary to force production during pedaling.

In short, the cyclists were more economical than the triathletes in all studied cadences, as well as having a lower cocontraction rate in almost all the analyzed situations.

In this regard, the hypothesis that cyclists would have a better technique than the triathletes was confirmed. The calculation of cocontraction index, as proposed by Winter (2005), used in conjunction with economy of movement may represent a more appropriate indicator for studying performance in cyclists and triathletes.

References


Marsh AP, Martin PE. Effect of cycling experience, aerobic power, and power output on preferred and most economical cycling cadences. Med Sci Sport Exerc 1997;29(9):1225–32.


Cláudia Tarragó Candotti is a researcher and assistant professor in the Physical Education Course and Physical Therapy Course at University of Vale do Rio dos Sinos – Brazil. She earned a Ph.D. in Human Movement Science at the Federal University of Rio Grande do Sul – Brazil. Her research focuses on postural aspects and neuromuscular analysis of human movement.

Jefferson Fagundes Loss is a professor in the Department of Physical Education at the Federal University of Rio Grande do Sul – Brazil. He earned an MSc in Mechanical Engineering and a Ph.D. in biomechanics from the same university. Dr. Loss served as Researcher and Professor of the Biomechanical Laboratory at the Federal University of Rio Grande do Sul where he is an Assistant Professor of Biomechanics. His research focuses on kinetic and kinematic analysis of human movement with specific interests in musculoskeletal effects.

Daniel Bagatini is a graduate in Physical Education at the Federal University of Rio Grande do Sul focusing on triathlon, training, fitness and athletic performance.

Denise Paschoal Soares is a graduate in Physical Education at the Federal University of Rio Grande do Sul. She earned a MSc in Human Movement Science at the same institution. Currently, she is doing a Ph.D. in Sports Science at the University of Porto in collaboration with Nike Research Lab.

Everton Kruel da Rocha is a graduate in Physical Education at the Federal University of Rio Grande do Sul. He earned an MSc in Human Movement Science at the same university. Currently, he is focus on indoor cycling.

Alvaro Reischak de Oliveira is a professor in the Department of Physical Education at the Federal University of Rio Grande do Sul – Brazil. He earned a Ph.D. in Biological Sciences at the same university. Dr. Oliveira focuses on physiology with emphasis on metabolic and cardiovascular adaptations to exercise.

Antonio Carlos Stringhini Guimarães was a professor in the Department of Physical Education at Federal University of Rio Grande do Sul – Brazil. He earned an MSc in Biomechanics at the University of Iowa and a Ph.D. in Kinesiology at University of Calgary. He died, cycling on the street, before this paper was accepted.