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Original Article

Changes in postural stability following strenuous running and cycling

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Abstract:
Different exercise protocols have been investigated considering the fatigue effects on postural control. However, the effects of cycling and running fatigue on postural stability are not clear. This study investigates whether, for a same group of participants, strenuous cycling and running could differently affect postural stability while standing. Fifteen men were submitted to measurements for center of pressure (COP) in both directions, antero-posterior (ap) and medio-lateral (ml), to assess stability before (PRE) and after (POS) strenuous bouts of running and cycling, randomly assigned. The COP length, COP area, COP RMSap and COP RMSml were calculated. Three trials (POS1, POS2, and POS3) lasting 30 s with 5 s interval between them were performed after exercises. Heart rate was recorded during the protocols. There were significant increases in COP length, COP area, COP RMSap, and COP RMSml after strenuous exercises. PRE differed from POS2 for COP area, COP length, COP RMSap, and COP RMSml after both running and cycling (all $p<0.05$) However, COP RMSml did not change significantly after cycling. After running, PRE differed from POS3 for COP length, COP area and COP RMSml, but were similar after cycling. Our results indicated that strenuous running negatively affects stability more than cycling. These effects were shortly reversed after cycling, but not after running. Also, an increase on mediolateral displacement means higher risk of falls in elders.
Key words: muscle fatigue, balance, cycle exercises.

Introduction

The central nervous system (CNS) has the ability to continuously regulate neuromuscular activity during standing by processing incoming sensory information from visual (Mergner et al. 2005), somatosensorial (Bove et al. 2003; Tresch 2007), and vestibular afferent pathways (Bacsi and Colebatch 2005) through a sensory-motor integration mechanism denominated postural control. This sensory-motor integration ensures that the projection of the center of gravity will be maintained within the body's base of support (Duarte and Zatsiorsky 2002).

Strenuous exercises and the associated neuromuscular stress may negatively influence the overall output of the postural system, as lower force outputs or reduced motor control (Bove et al. 2007; Forestier et al. 2002; Fox et al. 2008; Gribble et al. 2004; Nardone et al. 1997; Nardone et al. 1998). The current literature supports the concept that fatigue leads to higher instability while standing even for healthy people (Bove et al. 2007; Forestier et al. 2002; Fox et al. 2008; Nardone et al. 1997). Several investigations found changes in the center of pressure patterns (COP), which express the postural stability behavior during quiet standing. It has been found following strenuous intensity treadmill running (Lepers et al. 1997; Nardone et al. 1997) as well as stationary cycling (Derave et al. 1998; Vuillerme and Hintzy 2007). Strenuous cycling has been related to increases in COP amplitude (Lepers et al. 1997; Nardone et al. 1997), mostly in the antero-posterior direction (Derave et al. 1998; Gauchard et al. 2002; Nardone et al. 1997), while the effects of strenuous running on postural stability were moderate and lasted from 13 to 20 minutes (Fox et al. 2008; Nardone et al. 1998). However, these effects were not tested for the same participant performing both exercises.

The pattern of flexion/extension movements experienced in running and cycling are similar in some ways; both these locomotor tasks are cyclical; they require reciprocal flexion and extension of the hip, knee, and ankle involving alternated rhythmic muscle activation and deactivation of antagonists in a well-timed and coordinated manner. Nevertheless, running leads to a higher VO_2 max capacity since the muscle mass involved is known to be greater in running than cycling. Moreover, the role played by the plantarflexors muscles (mostly concentric on cycling and eccentric on running) may influence its activity during postural control. The different strategies of muscle recruitment found in the lower limbs when comparing running and cycling, such as torque production at different lengths observed for the *rectus femoris* (Herzog et al. 1991; Savelberg and Meijer 2003), could significantly influence postural control (Paillard et al. 2010). Finally, there are differences in kinematics of the ankle and knee between running and cycling (Martin and Brown 2009; Squadrone and Gallozzi 2009), which

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influence the active force production by the *gastrocnemius* (Herzog et al. 1990). Taken together, these differences on force generation and kinematics of lower limbs may elicit higher fatigue effects for running compared to cycling (Edwards 2007; Gribble et al. 2004).

Learning about the effects of muscular fatigue on postural stability after strenuous cycling and running exercises is important to develop a basic understanding about the effects of muscle fatigue induced by bilateral cyclical exercises on postural stability, mainly because muscle fatigue has been proposed to be a factor related to lower extremity injury (Chappell et al. 2005) and cycling and running are exercised widely suggested for patients and elderly looking for improvement or maintenance of physical conditioning.

Here we investigated the effects of strenuous cycling and running protocols on postural stability by assessing COP displacement in participants who performed both exercises' bouts. Our hypotheses were that (a) strenuous cycling would induce smaller changes in COP when compared to running, because during cycling the biarticular muscles (which are the more involved on postural control) are producing lower active force (working concentrically) than during running, therefore, minimizing the fatigue effects (Herzog et al. 1991). Additionally, (b) the effects of strenuous exercises (both cycling and running) on COP could be reverted quickly, considering the higher capacity of metabolic recuperation of the postural muscles.

Materials and methods

Participants

Fifteen male participants volunteered for this study after they gave their informed consent according to the institutional ethics committee and conformed to the Declaration of Helsinki. Participants presented mean ± standard-deviation age of 23 ± 5 years, height 1.79 ± 0.05 m and body mass 70.9 ± 7.3 kg (check table 1 for more details). All participants were neurologically intact, physically active, and they did not have any history of low back pain or lower limb injury, hip and spine, neither historic of cerebellar, vestibular or central nervous system diseases. Any participant has been systematically trained for any of the exercises.

Each participant performed one strenuous bout of running and cycling, which were randomly assigned and separated by 48 hours. The bouts were performed at the same time of the day. During both the protocols, heart rate (HR) was continuously monitored using a wireless heart rate monitor (S725, Polar Electro Oy, Finland). The intensity of both strenuous protocols was monitored using the predicted maximum HR values for the age (using *220-age* equation) (Tanaka et al. 2001). In both protocols participants were instructed to perform their very best, and were verbally encouraged throughout the trial to support the exercise as long as they could. Thereby, we defined exhaustion when the HR overtakes 90% of the maximal HR predicted for the age or voluntary exhaustion. The fatigue protocols were developed based on previous methods (Nardone et al. 1997).

Strenuous running protocol

The strenuous running protocol was performed using a motorized treadmill (ATL 1200, Inbramed, BRA). Participants completed three minutes of walking at 5 km/h aiming for warm-up, and then started an incremental protocol at velocity of 7 km/h. The treadmill velocity was increased 1 km/h every minute, without changes in treadmill inclination, until exhaustion. Protocol was based in the experiment described elsewhere (Bove et al. 2007), which found increased levels of fatigue after exercise.

*Strenuous cycling protocol*The strenuous cycling protocol was performed using a bicycle mounted on a cycle simulator that permitted to control the pedaling workload (Computrainer ProLab 3D, Racermate Inc., USA). Saddle and handlebar vertical and horizontal positions were adjusted for each participant prior to data collection according to the proper biomechanical positioning for cycling (Burke 1994). Participants were orientated to remain seated throughout the testing. The cycling protocol started with pedaling at 50 W during three minutes to warm-up. Immediately after the warm-up, an initial workload of 95 W was applied. Every minute, the workload was increased 35 W until exhaustion. Exhaustion was defined as the point when the participant was no longer capable of maintaining 70 revolution/min (rpm).

COP assessment

Postural stability was evaluated by monitoring the COP displacement in medial-lateral and antero-posterior directions before (PRE) and for three times immediately after (POS1, POS2, POS3) the bouts of strenuous exercise (Figure 1). All postural stability trials lasted 30 s. Measurement at POS1 started immediately after the strenuous protocol, and for the subsequent measurements (POS2 and POS3) a five seconds interval was conducted. During the five seconds intervals, participants stayed standing outside of the force platform.

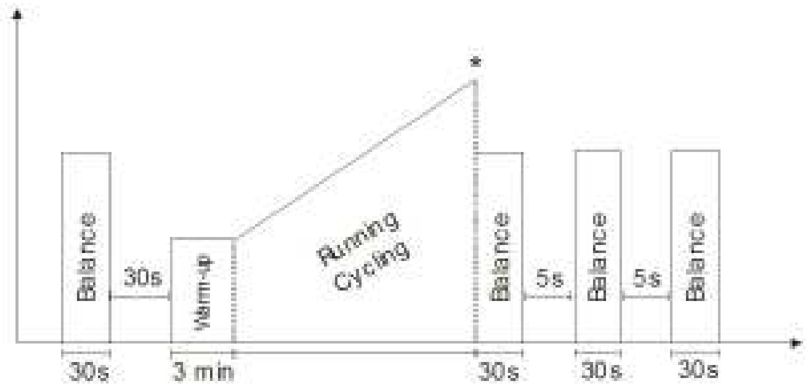

Fig. 1. Experimental design for balance assessments conducted before (PRE) and after (POS1, POS2, POS3) strenuous running and cycling. After PRE, participants performed the bout of strenuous exercise. Immediately after exhaustion, postural stability was assessed for three times (POS1, POS2, POS3) * The first postural stability evaluation pos exercise was immediately after exhaustion (figure is not in scale)

The COP displacements were monitored by means of a biomechanical 3D force plate (AMTI OR6 series, Advanced Mechanical Technology, Watertown, MA, USA) embedded at the level of the ground and positioned at the center of a quiet room. Data were acquired at a sampling rate of 100 Hz (Vuillerme et al. 2002). The participants were instructed to stand quietly avoiding unnecessary movements, with their feet apart at a comfortable width (shoulder-width apart), and with their arms relaxed at the anatomical position. They stood at the same position during 30 seconds while data were acquired. The foot positions were marked on the force platform for every participant and were the same for all trials. Data of postural stability (COP measurements) were acquired while the participants kept their eyes closed in an attempt to reduce the influence of visual information on the neuromuscular activity. Signals from the force plate were low-pass filtered using a second-order Butterworth filter with a cut-off frequency of 10 Hz (Vuillerme et al. 2002). COP was calculated considering ground reaction forces and moments across the three-dimensional axis using custom scripts written in Matlab® language (MATLAB 7.1, Mathworks Inc., Novi, MI, USA).

The variables used to express the COP behavior were: The ellipse area considering 95% of the data (COP area): it corresponds to the area comprehending 95% of the total COP displacements; The RMS for both directions (antero-posterior, COP RMSap; medial-lateral, COP RMSml): it corresponds to the standard-deviation around a middle point of the COP displacement, for each direction; COP length: distance covered by the COP. These variables express the COP behavior whereby an increase in these variables means an increase on instability (Prieto et al. 1996).

Statistical analysis

Data were analyzed using mean and standard-deviation. Data normality, sphericity, and equality of variances were verified using Shapiro-Wilk's, Mauchly's, and Levene tests, respectively. Comparisons were accomplished by ANOVA considering exercise (running and cycling) and time frame (PRE, POS1, POS2, POS3) with a Bonferroni correction for multiple comparisons. Where main effects were found, the comparisons between exercises for COP length, RMSap, RMSml and COP area, duration of protocols and HR values were accomplished using independent t-tests. Significance level was set at 0.05 for all data analysis using SPPS v13.0 (SPSS Inc., Chicago IL, USA).

RESULTS

Exhaustion evidences

The resting HR prior to each exercise did not differ between tests for both running and cycling [$t_{(14)}$ = -0.143; p = 0.888]. Duration of exercise was greater for cycling than running [$t_{(14)}$ = -3.713; p = 0.02]; table 1). Any feeling of dizziness was reported by the participants at the end of the trials. HR maximal at exhaustion protocols exceeded 90% of maximal age-predicted for all participants in both exercises (average maximal heart rate HR_{max} for both protocols was 195 ± 8 bpm). It corresponded to 94 ± 3% of HR_{max} for running, and 93 ± 8% of HR_{max} for cycling. For both exercises, HR increased significantly throughout the protocol [$t_{(14)}$ = -23,94; p < 0.001]. These results ensure that participants performed maximal effort in both strenuous protocols.

Table 1. Mean and standard-deviation (SD) of age (years), height (m), body mass (kg), maximal heart rate predicted by age (bpm), heart rate at resting before running exercise (HRrest Running, bpm), maximal heart rate during running (HRmax Running, bpm), time of running exercise (min), heart rate at resting before cycling

exercise (HRrest Cycling, bpm), maximal heart rate during cycling (HRmax Cycling, bpm), time of cycling exercise (min)

	HRmax (bpm)	HRrest Running (bpm)	HRmax Running (bpm)	Running time (min)	HRrest Cycling (bpm)	HRmax Cycling (bpm)	Cycling time (min)
Mean	*196*	*69*	*184*	*9.7*	*69*	*182*	*11.7**
SD	*5.0*	*9.8*	*7*	*1.9*	*9.8*	*13*	*1.4*

* Statistical significant different of running [$t_{(14)} = -3.713$; $p < 0.01$]

COP comparison between exercises

COP length, COP area, COP RMSap and COP RMSml ($p < 0.05$) were similar in the evaluation PRE for both exercises. After strenuous bouts of exercise, there were significant effects on the postural stability (POS1, POS2 and POS3), which were different between running and cycling.

Considering comparison between effect of the two exercise protocols, there were statistically significant differences for POS1 COP length [$t_{(28)} = -2.408$; $p = 0.027$], COP area [$t_{(28)} = -2.450$; $p = 0.027$] and COP RMSml [$t_{(28)} = -2.688$; $p = 0.016$], but not for COP RMSap [$t_{(28)} = -2.450$; $p = 0.027$]. However, any statistically significant differences between exercises were found for POS2 (COP length [$t_{(28)} = 3.207$; $p = 0.678$], COP area [$t_{(28)} = 7.909$; $p = 0.238$], COP RMSap [$t_{(28)} = 1.057$; $p = 0.989$], and COPRMSml [$t_{(28)} = 3.359$; $p = 0.191$]). Comparing running and cycling at POS3, statistically significant differences were found for COP length [$t_{(28)} = -2.284$; $p = 0.034$], COP area [$t_{(28)} = -2.132$; $p = 0.042$] and COP RMSml [$t_{(28)} = -2.283$; $p = 0.030$], but not for COP RMSap [$t_{(28)} = 6.521$; $p = 0.085$].

COP comparison between trials

COP changes during the recovery period did differ between the exhaustion protocols as denoted by the comparison between PRE, POS1, POS2 and POS3. The COP length differed significantly between PRE and POS1 [$F_{(3)}=13.332$; $p = 0.001$], POS2 [$F_{(3)} = 13.332$; $p = 0.027$] and POS3 [$F_{(3)} = 13.332$; $p = 0.01$] after running. Additionally, three minutes after running (POS3), body balance still significantly altered when compared to the resting condition. On the other hand, after strenuous cycling, PRE was significantly different of POS1 [$F_{(3)} = 9.313$; $p = 0.005$] and POS2 [$F_{(3)} = 9.313$; $p = 0.003$], without statistically significant differences at POS3 [$F_{(3)} = 9.313$; $p = 0.999$] (Figure 2).

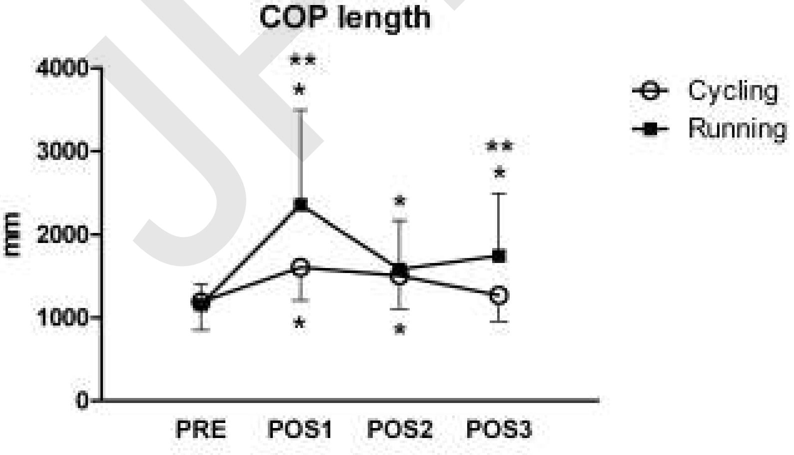

Fig. 2. COP length before (PRE) and after (POS1, POS2 and POS3) running and cycling (*statistical significant different from PRE, p<0.05; **statistical significant difference between effects of strenuous cycling and running, p<0.05)

COP area differed between PRE and POS1 [$F_{(1.387)} = 11.552$; $p = 0.01$], POS2 [$F_{(1.387)} = 11.552$; $p = 0.002$] and PRE and POS3 [$F_{(1.387)} = 11.552$; $p = 0.007$] for running protocol. After strenuous cycling COP area in PRE was statistically different from POS1 [$F_{(3)} = 9.313$; $p = 0.011$] and POS2 [$F_{(3)} = 9.313$; $p = 0.003$] but PRE did not differ from POS3 [$F_{(3)} = 9.313$; $p = 0.877$] (Figure 3).

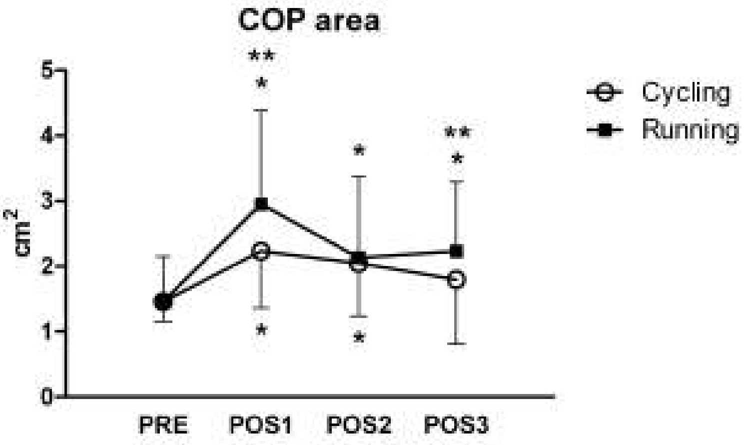

Fig. 3. COP area before (PRE) and after (POS1, POS2 and POS3) strenuous running and cycling (*statistical different from PRE, p<0.05; **statistical difference between effects of running and cycling, p<0.05)

After strenuous running, COP RMSap was different between PRE and POS1 [$F_{(3)}$ = 7.711; p = 0.003] and POS2 [$F_{(3)}$ = 7.711; p = 0.031], but not for POS3 [$F_{(3)}$ = 7.711; p = 0.058]. Similar results were found after cycling, where PRE did statistically differ from POS1 [$F_{(3)}$ = 7.422; p = 0.022] and POS2 [$F_{(3)}$ = 7.422; p = 0.008], but not of POS3 [$F_{(3)}$ = 7.422; p = 0.999] .COP RMSml showed differences when PRE was compared with POS1 [$F_{(1.555)}$ = 10.908; p = 0.008] and POS3 [$F_{(1.555)}$ = 10.908; p = 0.012] but not for POS2 [$F_{(1.555)}$ = 10.908; p = 0.063] after running; after cycling when compared PRE with POS1 [$F_{(3)}$ = 4.369; p = 0.123], POS2 [$F_{(3)}$ = 4.369; p = 0.221] and POS3 [$F_{(3)}$ = 4.369; p = 0.276], any statistical difference was found (figure 5).

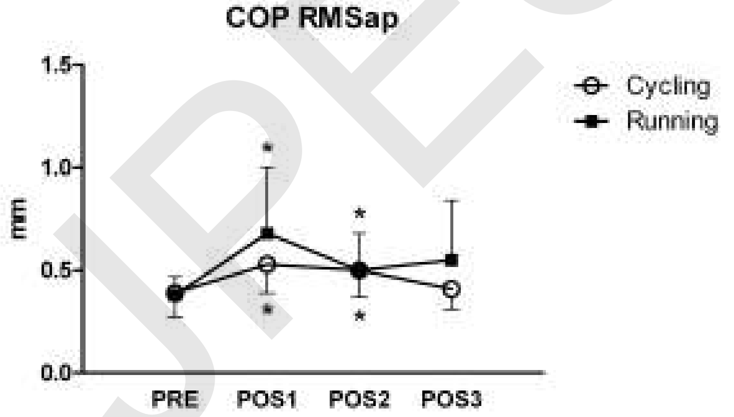

Fig. 4. Results of COP RMSap before (PRE) and after (POS1, POS2 and POS3) running and cycling (*statistical different from PRE, p<0.05; **statistical difference between effects of running and cycling, p<0.05)

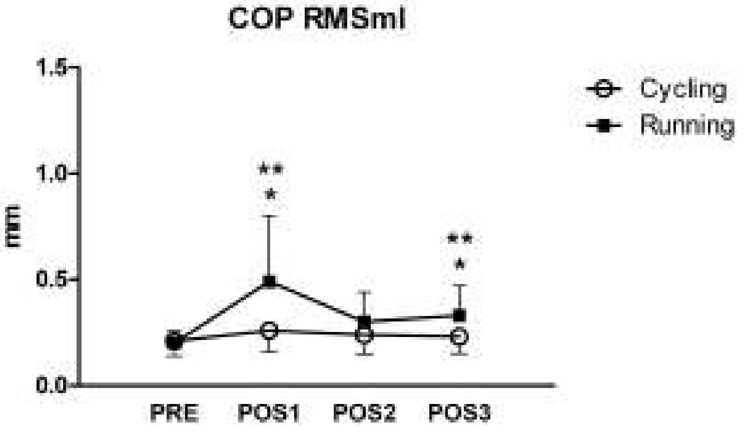

Figure 5. Results of COP RMSml before (PRE) and after (POS1, POS2 and POS3) running and cycling (*statistical different from PRE, p<0.05; **statistical difference between effects of running and cycling, p<0.05)

Discussion

Strenuous treadmill running and stationary cycling at intensities above anaerobic threshold negatively affects important parameters of postural stability, mostly for COP area and COP length (Nardone et al. 1997). Differences in the muscle mass involved (Carter et al. 2000), functional role played by the muscles crossing ankle joint (Ijkema-Paassen and Gramsbergen 2005) as well as different ankle and knee kinematics between running and cycling (Martin and Brown 2009) influencing the capacity of force production, for instance, for gastrocnemius medialis (Herzog et al. 1990), may help to explain the differences found here. We tested a group of healthy participants performing strenuous running and cycling exercises and measured body balance before and after exhaustion. The main findings were related to similarity in the COP parameters (area, length and RMSap) immediately after exhaustion due to running or cycling, but exercise-dependent behaviors were observed during the recovery period for few minutes after the end of strenuous bouts. Surprisingly, after strenuous running we found differences in RMSml, but not after cycling. In general, recovery of postural stability was faster after strenuous cycling than running.

These data suggest that running and cycling may require different recovery time to restore postural stability. Exhaustion protocol resulted in significantly longer effects in postural stability, which was significantly minimized in a short period of recovery, especially after cycling. Fox et al. (2008) found that postural stability after running exhaustion protocol requires between 8 to 13 minutes to achieve baseline levels. Nardone et al. (1998) found that body instability induced by cycling and running still higher than baseline up to 20 minutes after ending the exercise. These results of both studies are not in agreement with our findings. We observed similar COP responses between PRE and POS3 after cycling, which suggested ability to restore body balance in a short time after an exercise mostly involving lower limbs. However, POS3 presented COP significantly increased from PRE after running, which involves a higher muscle mass during performance.

The strenuous cycling and running leading to muscular fatigue are likely related to the deficiency of central processing of proprioceptive signals, which means, caused by central fatigue processes. Central fatigue may significantly decreases the precision of motor control, interrupt voluntary muscle-stabilizing activity to resist imparted joint forces, and finally affects postural stability, increasing the risk of injury (Miura et al. 2004). In this case, CNS may use information from other afferents pathways like vestibular system and/or somatosensory system from the neck to reduce the effects of muscle fatigue on the postural stability (Vuillerme and Cuisinier 2009). It has been shown that muscle fatigue also affects information processing from proprioceptive organs, e.g., Golgi’s tendon organ (Lagier-Tessonnier et al. 1993), and the activity of different types of mechanoreceptors type I and II, which could also explain the results, since they have different functions such as control of joint sense position; as well as monitoring timing of start and end of movement by affecting intrafusal muscle fibers (Macefield 2005). Our results suggest that fatigue effects of running can longer persist when compared to cycling, especially in the medio-lateral direction. The longer effects of fatigue on COP RMSml after running could be associated to a higher risk for falls (Anker et al. 2008).

An explanation for the faster recovery after cycling rather than running could be related with different characteristics of force production between exercises. While the movement pattern and muscular activation are similar between running and pedaling, force production can be different. In cycling, *rectus femoris* may produce more force at shorter lengths (Herzog et al. 1991; Savelberg and Meijer 2003). In other hand, during running, more force needs to be produced by the *rectus femoris* at longer lengths (Herzog et al. 1991) using a greater portion of muscle passive components and generating force eccentrically (Gandevia et al. 1995). After cycling, these passive elastic components could work more effectively for postural stability (Loram et al. 2007). Tendons (passive elastic components) can present high participation in muscle stretching for lower levels of force production such as experiences while standing (Magnusson et al. 2008).

Someone may question regarding the influence of respiratory rate on body sway. The respiratory rate even though increased after a strenuous exercise has little influence on body sway (Schmid et al. 2004). According to Jeong (1991), the respiratory rate has to be twice as found in rest in order to increase COP displacement in 120%. Nardone et al. (1997) presented data regarding an increase on respiratory rate of approximately 20% higher than pre-exercise values after strenuous running and cycling. Therefore, we expect only minor changes in body sway after running and cycling due to changes in respiratory rate.

A possible limitation of the present study was not presenting additional physiological parameters such as oxygen uptake or blood lactate concentration during strenuous testing to quantify fatigue. However, the assessment of several indicators of fatigue simultaneously would make postural stability assessments after exhaustion difficult to be properly achieved.

Conclusion

Strenuous running has longer effects in the parameters of postural stability than observed after strenuous cycling. Understanding the effects of strenuous cyclic exercises on postural stability is important because running and cycling are exercises often employed as strategies used as training therapies to minimize risk of falls in elderly or as recovery protocols after lower limb injuries. Further studies should quantify muscular activation combined with kinetic and kinematic analysis in trained and injured participants.

Acknowledgments and authors' contributions

All authors contributed to this manuscript. Carlos Bolli Mota and Felipe P Carpes obtained funds and supervised data collection. Fernando Diefenthaeler designed the fatigue protocol. Matheus Joner Wiest collected the data, conducted the statistical analysis and drafted the manuscript which was reviewed and approved by all authors. This study was supported by grants received from FAPERGS-Brazil (grant number 07517932).

Conflicts of interest - The authors have declared that no conflict of interest exists.

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