EFFECTS OF TRICEPS SURAE FATIGUE ON GAIT LOCAL DYNAMIC STABILITY IN WOMEN AS PRACTITIONERS AND NON-PRACTITIONERS OF STRENGTH TRAINING

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This study evaluated the effects of plantar flexors fatigue on gait local dynamic stability in young women. Strength-training practitioners (n = 20), and non-practitioner women (n = 21) performed a 4-min treadmill walking before and after a unilateral fatigue protocol of the triceps surae. The major findings of the study demonstrated that localized fatigue did not affect the local dynamic stability, independent of the participant's training condition. Participants appear to be able to cope with muscle fatigue, adapting to maintain gait performance. Even so, the need for a recovery interval should be considered in order to minimize the risk of injuries and falls in individuals susceptible to muscle fatigue in sports.

KEY WORDS: human gait, gait stability, muscle fatigue, training.

INTRODUCTION: Muscle fatigue is defined as a loss of the contractile capacity of the muscle as consequence of muscle activity. There is a decrease in force production capacity or a failure to continue working at a given exercise intensity (Bigland-Ritchie & Woods, 1984). The inevitable consequence of muscle fatigue is a decrement of movement performance (Cortes, Onate, & Morrison, 2014). For instance, the proprioception and gait variables can be altered due to triceps surae fatigue, since this muscle has a primary role on locomotion (Graham, Rice, & Dalton, 2016).
The relatively transient effects of muscle fatigue can have negative long-term consequences, such as an adverse effect on neuromuscular control, which could lead to functional instabilities, risk of an injury (Cortes, Onate, & Morrison, 2014), and increased risk of falls (Parijat & Lockhart, 2008).
Fatigue following various types of exercises has been found to alter gait stability (Toebes et al. 2014; Hamacher et al. 2016; Vieira et al. 2016). A method to assess gait stability includes the estimation of local dynamic stability (LDS), which is derived from nonlinear dynamic system theory and defined as the ability of the locomotor system to resist to small perturbations (Bruijn, Meijer, Beek, & Dieën, 2013).
The assessment of muscle fatigue effects on gait stability is important to avoid falls, slips and injuries, and to improve people's quality of life. In addition, identifying the fatigue effects of a specific muscle group on gait stability may help to prescribe more effective conditioning and rehabilitation protocols. Thus, the aim of this study was to assess the effects of triceps surae fatigue on gait stability in women practitioners and non-practitioners of strength training.

METHODS: The study included 20 young women who were strength-training practitioners [practitioners group (PG) – 22 ± 3.27 years old, 1,60 ± 0,04 m, 57,10 ± 6,35 kg] and 21 young women who were not practitioners [non-practitioners group (NG) – 21.76 ± 3.01 years old, 1,62 ± 0,05 m, 62,35 ± 8,50 kg]. The strength-training practitioner women had been performing strength training for at least four months, while the non-practitioners women had been idle for at least four months. They were without functional impairments, pain, or orthopaedic pathologies within the past six months (self-declared). All subjects signed an informed consent document. The study was approved by the local ethical committee.
Experimental procedures and equipment: Firstly, the participants walked for 8 min on a level treadmill (Proaction BH Fitness, Brazil). The first 5 min were used to warm-up and to become familiar with the treadmill, and the final 3 min were used to evaluate each participant's preferred walking speed (PWS) (Dingwell, & Marin, 2006).

The kinematic analysis was performed using a 3-D motion capture system, comprising 10 infrared cameras operating at 100 Hz (Vicon Nexus, Oxford, UK). The reflective markers were positioned on the heels and the T1 vertebrae.
The participants walked for 4 min at PWS during the pre-fatigue period (PreF). Next, they performed the fatigue protocol and immediately after they walked for 4 min at PWS (PostF).
Muscle fatigue was induced in the triceps surae using a unilateral protocol on dominant leg. The participants were asked to rate their perceived exertion pre/post-fatigue according the Borg scale.
Data analysis: The parameters were calculated for the intermediate 150 strides for each trial, discarding the initial and final 15 seconds. All steps were detected as the zero-cross of the heel-marker velocity. LDS was assessed computing a divergent exponent, the largest Lyapunov exponent (λs), using Rosenstein's algorithm (Rosenstein, Collins, & Luca, 1993). LDS assumes that motor control ensured a dynamically more stable gait if the divergence exponent remained lower between trajectories.
Statistical analysis: After checking for normal distribution (Shapiro-Wilk test), the main effect of fatigue was verified by Student's t-test. The level of fatigue between the groups was compared using Mann-Whitney test. For intra-group comparison was used Wilcoxon test, with Bonferroni correction applied. The statistical analysis was conducted in R software (version 3.3.2), with $p \leq 0.05$.

RESULTS: The PGs and NGs were similar in age and height and different with respect to body mass and practice time. The protocol fatigue results are shown in Table 1. Before fatigue values are significantly different from after fatigue values in both groups ($p < 0.001$). Figure 1 shows the divergent exponent (λs) values.

Table 1. Characteristics of the groups in the protocol fatigue.

Characteristic	Practitioners Group (n = 20)	Non-practitioners Group (n = 21)
Initial repetitions in the fatigue protocol	24.65 ± 9.83*	20.47 ± 4.89*
Final repetitions in the fatigue protocol	13.80 ± 4.61*	14 ± 3.42*
Rate of perceived exertion PreF	9.52 ± 1.83*	10.57 ± 2.61*
Rate of perceived exertion PostF	18.05 ± 1.35*	17.78 ± 1.78*

Values are means ± standard deviation. *Significantly different. PreF, before fatigue protocol; PostF, immediately after fatigue protocol.

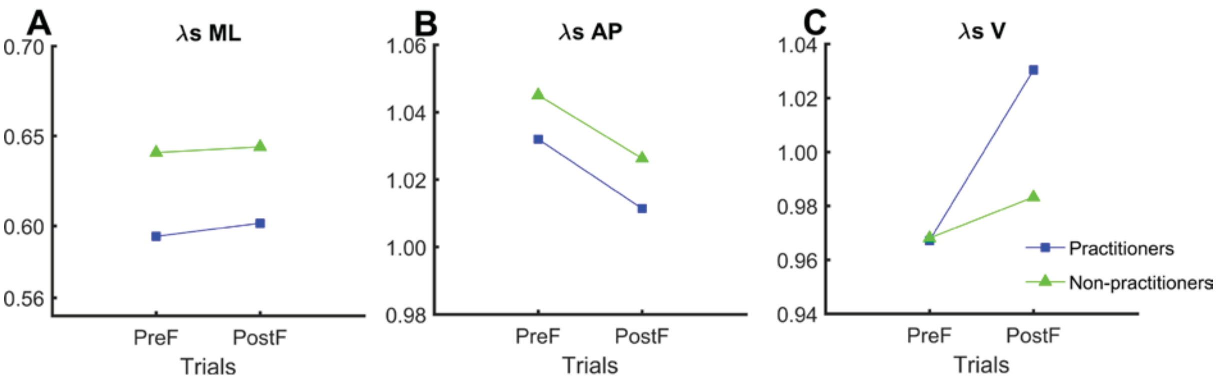

Figure 1. Largest Lyapunov exponent (λs). (A) ML, medial-lateral direction; (B) AP, anterior-posterior direction; (C) V, vertical direction. PreF, before the fatigue protocol; PostF, immediately after the fatigue protocol.

DISCUSSION: The effect of fatigue was not significant in all directions of the local dynamic stability. These unexpected results can be related to biomechanical changes or to neural control changes (Gates & Dingwell, 2011) that allowed for gait adaptability with localized fatigue. However, although not significant, an improvement of local dynamic stability in anterior-posterior direction was observed after triceps fatigue. Although the frontal plane is more important in the regulation of dynamic balance control (Terrier & Reynard, 2015), in our study, the sagittal plane was important since the fatigued muscles, located in the posterior muscle chain, acted in the anterior-posterior direction during gait push-off phase. Both groups showed a decrease for λs anterior-posterior (Fig. 1B).
One possible explanation for the stability improvement was that the participants became more cautious after fatigue, especially because the fatigued muscle was responsible for gait propulsion, a situation that would require an active control to stabilize the body in anterior-posterior direction. Our findings were consistent with some studies in the literature (Hamacher et al., 2016; Toebes et al., 2014) demonstrating that the participants were able to cope actively with the presence of fatigue.
Our fatigue protocol was effective in taking into account the rate of perceived exertion (Table 1). In contrast, our results indicated that there were no differences regarding training condition between the groups. The same results were found between active and non-active young adults (Barbieri, dos Santos, Vitório, van Dieen, & Gobbi, 2013), and with patients with Parkinson's disease and healthy individuals, grouped according to physical activity level (Santos et al., 2016). Both studies compared kinematic and kinetic parameters.
A possible explanation for the lack of difference between groups was the fact that triceps surae is not very energetically demanding and is not substantially large, so that an increase in both breath and heart rates were not to be expected, as could be for larger muscles in which the training condition could influence the results significantly (Bizid et al., 2009).
The present study have limitations, such as the use of a treadmill, which may have influenced the results. Future studies should investigate the progress of recovery after muscle fatigue in populations that have an increased fall or injury risk, such as athletes.

CONCLUSION: The participants were able to cope with substantial fatigue, prioritizing performance and safety of gait. The effects of plantar flexors fatigue appear not to be influenced by the participants' physical conditioning. It is suggest that training programs should include fatiguing exercises to adapt to the presence of fatigue, and that in the practice, the professionals should pay attention to the effects of fatigue in order to obtain better results.

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