Journal of
Functional Morphology and Kinesiology

MDPI

Communication

Influence of Trunk Extensor Muscles Fatigue on the Postural Control and Sensorimotor Integration

José Alberto dos Santos Rocha [1], Uanderson Silva Pirôpo [1,2], Rafael da Silva Passos [1], David Lomanto Couto [1], Alice Miranda dos Santos [1], Ana Maria Barbosa Argolo [1], Helder Brito Andrade [1], Cezar Augusto Casotti [2] and Rafael Pereira [1,2,*]

1 Research Group in Neuromuscular Physiology, Department of Biological Sciences, State University of Southwest Bahia (UESB), 45210-506 Jequié, Brazil; alberto26.ja@gmail.com (J.A.d.S.R.); uamder_som@hotmail.com (U.S.P.); rafaelspassos08@gmail.com (R.d.S.P.); davidlomanto01@hotmail.com (D.L.C.); alice_miranda08@hotmail.com (A.M.d.S.); ana.bafisio@gmail.com (A.M.B.A.); andrade.helder.b@gmail.com (H.B.A.)

2 Postgraduate Program in Nursing & Health, State University of Southwest Bahia (UESB), 45210-506 Jequié, Brazil; cacasotti@uesb.edu.br

* Correspondence: rpfisiologia@gmail.com; Tel.: +55-73-3528-9616

Academic Editor: Giuseppe Musumeci
Received: 15 October 2016; Accepted: 26 December 2016; Published: 13 January 2017

Abstract: This study aimed to investigate the effect of trunk extensor muscles fatigue, through a submaximum and time-limited isometric task, on the postural control and sensorimotor integration of young healthy adults. Previously and after a submaximum and time-limited isometric fatigue protocol of trunk extension muscles, 30 s stabilometric recordings were taken in both conditions: eyes opened and closed. The center of pressure (CoP) displacement in the anteroposterior (AP) and mediolateral (ML) directions, as well as the total displacement (TD) of CoP were analyzed from the recordings with both conditions (eyes opened and closed) and moments (PRE and POST fatigue protocol). Additionally, the Romberg Index was calculated for CoP displacement in the AP and ML directions, as well as for TD PRE and POST fatigue protocol. Significant differences between the studied parameters of pre- and post-fatigue protocol were not observed. The applied fatigue protocol was not able to modify the postural control, as well as the capacity of integrating sensorial information in the absence of vision, of young healthy subjects. These results indicate that proprioceptive information remains reliable after the used fatigue protocol, allowing subjects to keep a satisfactory straight posture.

Keywords: postural control; sensorimotor integration; fatigue

1. Introduction

Postural control involves the maintenance of balance and body orientation during straight posture, which is essential to many daily life activities and to physical and sports practices [1].

Balance maintenance depends on sensorimotor integration, involving the sensorial input coming from the skin, joint and muscle receptors (e.g., proprioceptors), as well as from the vestibular and visual receptors, to the central nervous system, where this afferent information is integrated to generate an adequate motor response [2]. Temporary modifications, such as a simple change or removal of one of the sensorial systems (e.g., closing eyes, standing on an unstable surface, or muscle fatigue), or permanent modifications as observed in blindness, sensorial nerve injuries, the aging process [3], and joint and/or muscle injuries, may compromise the postural stability. Such modifications make postural control ineffective, limiting the performance of daily life activities and physical or sports activities.

Stabilometry is a technique designed to record the center of pressure (CoP) displacements, allowing the evaluation of balance in the standing posture [1,4]. Owing to the close relation between the CoP and the center of gravity (CoG) of the body, the stabilometry allows us to objectively estimate the position of the CoG, as well as its small oscillations [1,5]. Then, it is plausible to use the stabilometric analysis to investigate the effect of conditions that modify sensorimotor integration [6].

In this context, muscle fatigue is an important condition that compromises sensoriomotor integration and, therefore, postural control. The fatigue of postural muscles, such as the lumbar trunk extensors, may occur in many labor conditions demanding high tension in this muscle group [7–10]. Such tension represents an important compromising factor of the spine's alignment and stability, inducing lumbar discomfort or pain [11]. This whole process may cause impairment in postural control and lead to orthopedic injuries.

A growing number of studies have reported impairments in postural control after fatigue protocols, especially when involving the lumbar trunk extensors [12–16]. The majority of these studies, however, induce fatigue through dynamic protocols carried out until muscle exhaustion. This model limits the applicability of its results to labor conditions, where tasks demand submaximal contractions, sustained in standing posture during limited periods of time. Thus, this study aimed to investigate the influence of postural muscles fatigue, induced by a submaximal isometric and time-limited task, on the postural control of healthy subjects.

2. Methods

2.1. Sample

Eight men (22.75 $\pm$ 8.04 years; 173 $\pm$ 61.16 cm; 75.88 $\pm$ 26.83 kg) volunteered to participate in this study. They were informed about all the experimental procedures, and signed an informed consent. The ethical approval was given by the State University of Southwest Bahia Ethics Committee (protocol number: 16054313.7.0000.0055).

All volunteers denied having neuromuscular disease or orthopedic injuries in lower limbs and/or spine. Besides, they were asked to avoid any kind of vigorous physical activity prior to the experiments.

2.2. Stabilometric Recording and Analysis

The volunteers were submitted to a postural control evaluation in stance position through a piezoelectric force platform (Footwork Pro AM CUBE, Gargas, France) with a sampling rate of 40 Hz. The coordinates of the body's CoP were recorded for 30 s of quiet barefoot standing. Volunteers remained with the arms relaxed along the body, heels 6 cm apart, and feet at an angle of 30° from each other. These procedures were adopted to ensure that the volunteers would have the same feet position in all records. During the recordings with eye opened, a target was placed at eye level 2 m in front of them, for visual reference purpose.

Two stabilometric records were carried out previously and immediately after the fatigue protocol: one with eyes opened (EO) and the other with eyes closed (EC), following a random order. It was adopted one minute rest interval between two consecutive records to minimize the recovery period after the fatigue protocol. Notwithstanding, a recording duration of 30 s is enough for reliable measures of postural oscillation [12,17].

The body's CoP displacement was analyzed in MATLAB® software (Mathworks, Natick, MA, USA) with previously developed routines to obtain four stabilometric parameters: amplitude displacement of the CoP in anteroposterior (AP_Amp; cm) and mediolateral (ML_Amp; cm) directions, total displacement (TD; cm) of CoP, as well as the mean velocity (MV; cm/s) of CoP displacement. These three parameters were obtained for EO and EC conditions, and the Romberg index (RI), defined as the ratio of CoP displacement in EO and EC was also obtained for the PRE and POST fatigue recordings. Romberg index is widely used to evaluate the contribution of vision to postural stabilization, so that greater values indicate a greater dependence of visual cues and/or a poor

confidence in the proprioceptive cues. Romberg index was calculated for each stabilometric parameters (i.e., AP_Amp; ML_Amp, TD and MV).

2.3. Fatigue Protocol

Two maximum voluntary isometric contractions (MVIC) of the trunk extension were performed in a device previously validated by Kawano et al. [18]. In order to record the isometric force, a force transducer (EMG System Brasil, São José dos Campos, Sao Paulo, Brazil) was used. The MIVC were sustained for 3 s each with a 60 s rest interval. The best performance, defined as the biggest force generated in the two MVIC, was used to calculate 60% of the MVIC. This value was used then in the fatigue task, as proposed previously by Kavanagh et al. [19].

The isometric fatigue model proposed by Kavanagh et al. [18] induces the lumbar trunk extensors fatigue, and was carried out in the same device used to obtain the MICV. This fatigue protocol comprises a 30 s submaximum contraction period, at 60% of the MICV, followed by a 30 s rest period and then, more 20 s contraction period with the same intensity as before. The isometric force data was displayed in real time on a laptop screen placed right in front to the subjects, allowing to the visual feedback.

Figure 1 presents a schematic view of the experimental procedures, which involved the CoP recordings before and immediately after the isometric fatigue protocol.

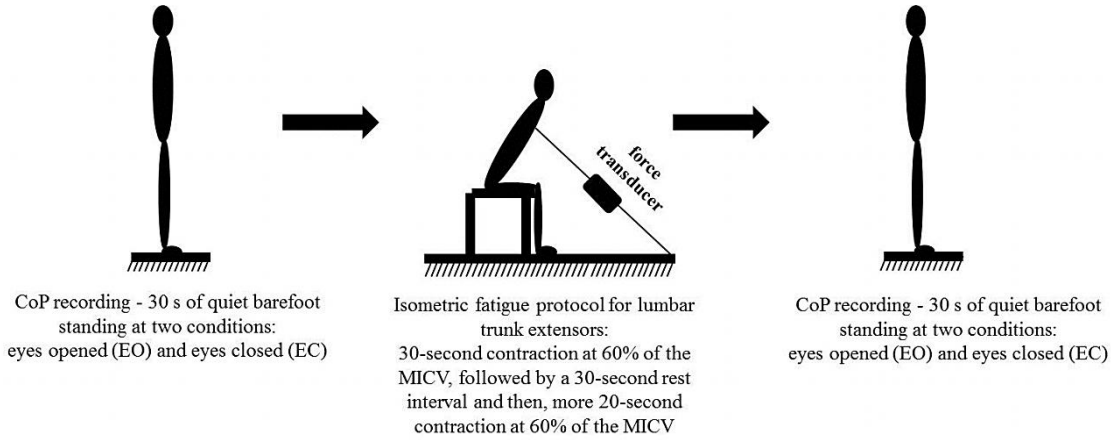


Figure 1. Schematic view showing the sequence of stabilometric recordings before and immediately after the isometric fatigue protocol.

2.4. Statistical Analysis

The results are presented as mean ± standard deviation (SD). Shapiro-Wilk test was used to verify if parameters are normally distributed. Since the stabilometric parameters were normally distributed, the Student's *t*-test was used to compare the stabilometric parameters obtained PRE and POST fatigue protocol. All statistical procedures were performed with SPSS 21.0 (SPSS Inc., IBM, Chicago, IL, USA) and a significance level of $p < 0.05$.

3. Results

No significant differences were observed between PRE and POST fatigue protocol measures for AP_Amp and ML_Amp obtained in EO and EC conditions ($p > 0.05$) (see Table 1). Similarly, the Romberg Index did not show significant differences between PRE and POST measures ($p > 0.05$) (see Table 2).

Table 1. Mean ± SD of amplitude displacement of the center of pressure in anteroposterior (AP) and mediolateral (ML) directions, as well as the total displacement (TD) and mean velocity (VM) of Center of Pressure, during eyes opened and closed, previously (PRE) and immediately after (POST) a trunk extensors fatigue protocol.

Stabilometric Parameter	Eyes Opened		Eyes Closed	
	PRE	POST	PRE	POST
AP Amplitude (cm)	1.96 ± 0.49	1.92 ± 0.54	2.34 ± 0.58	1.93 ± 0.54
ML Amplitude (cm)	1.30 ± 0.32	1.27 ± 0.17	1.44 ± 0.35	1.27 ± 0.17
TD (cm)	380.59 ± 106.67	378.34 ± 113.43	455.72 ± 112.52	403.76 ± 163.82
MV (cm/s)	6.48 ± 1.64	6.72 ± 2.02	7.26 ± 2.09	6.92 ± 1.87

Table 2. Romberg indexes from anteroposterior (AP) and mediolateral (ML) displacement, Total Displacement (TD), and mean velocity (VM) of Center of Pressure, obtained previously (PRE) and immediately after (POST) a trunk extensors fatigue protocol.

Stabilometric Parameter	PRE	POST
ROMBERG_AP	1.26 ± 0.45	1.15 ± 0.45
ROMBERG_ML	1.16 ± 0.39	1.07 ± 0.42
ROMBERG_TD	1.23 ± 0.28	1.10 ± 0.39
ROMBERG_MV	1.13 ± 0.23	1.04 ± 0.08

4. Discussion

This study aimed to investigate the influence of postural muscles fatigue, induced by a submaximal isometric and time-limited task, on the postural control of healthy subjects, and our results suggest that the applied fatigue protocol was not able to modify the postural control of young healthy individuals or the capacity to integrate sensorial information, since the absence of vision did not impair the stabilometric parameters.

The effects of muscle fatigue on postural control are dependent on the muscle group involved in the task and the applied fatigue protocol (e.g., type, duration and intensity of contraction, etc.). Paillard [20] confirmed that fatigue protocols carried out at submaximum intensity can lead to postural control impairments only if sustained for long periods, such as in exhaustion-limited protocols (e.g., when the subject is unable of keeping the task), which, in turn, could be independent of the involved muscle groups.

Indeed, there is a decline in the muscle force output during exhaustion conditions, compromising the ability of the musculoskeletal system to adjust the body posture precisely. Previous studies have shown that declines bigger than 30% of the maximum isometric force after a fatigue protocol are enough to compromise postural control [14,20]. Notwithstanding, small reductions in the isometric force (~5%) can compromise postural control only when kept for long time periods, as demonstrated by Paillard et al. [21], suggesting a close relationship of this fact with changes in the facilitation/inhibition status from the spinal cord neurons.

Similarly, muscle metabolites produced during tasks until exhaustion (i.e., task failure) may also contribute to postural control impairments [20]. The muscle metabolites stimulate group III and IV afferent fibers, which inhibit motoneurons of active muscles during the task [22–24]. Thus, the motor command accuracy would be compromised [24], which could also impair postural control, especially if the postural muscles are involved in the fatiguing task.

In this context, the fatigue protocol applied in this study was not able to induce muscle exhaustion, being chosen due to its intermittent feature (i.e., contraction periods intercalated by a resting period), inducing lumbar trunk extensor fatigue without compromising the strength generation capacity in submaximum conditions [19,25] or without promoting the accumulation of metabolites, mimicking many real labor conditions. Therefore, based on the absence of postural control impairments

with or without vision, it can be stated that the applied protocol was not able to induce changes in the sensorimotor integration and a decline in the muscle strength, both of which are needed to maintain posture.

The absence of differences in the Romberg Index suggests that the sensoriomotor integration remains satisfactory after this exercise protocol, since in the conditions without vision, there is a trend to increase CoP oscillation, increasing the weight of proprioceptive information to maintain adequate postural control. Thus, the results presented in this study allow us to indicate that the proprioceptive information remains reliable for maintaining the posture after the used fatigue protocol. It is interesting to note that Kavanagh et al. [19] observed changes in the dynamic postural control (i.e., during the gait) after applying the same protocol, suggesting a reorganization of postural adjustments to provide better head stability during gait. In contrast, we used a static postural analysis and verified that, in such circumstances, postural control is not modified after this fatigue protocol.

Despite the relevance of our finding in the clinical and scientific fields, it is important to state that the small sample size and the absence of the control of confounding factors that influence the postural control, such as stress [26], are weakness of our study, which should be considered in further studies.

5. Conclusions

Our results show that the applied fatigue protocol was not able to modify the postural control of young healthy subjects, nor their capacity to integrate sensorial information in the absence of visual information. In sum, the results indicate that proprioceptive information remains reliable after this fatigue protocol without impairment in postural control.

It is important to note that our results shed light on the importance of considering the used method to induce fatigue when analyzing and interpreting the influence of muscle fatigue on postural control, since conditions of muscle exhaustion may induce inhibitory effects on the central nervous system and its capacity of sensorimotor integration. Additionally, muscle exhaustion conditions are more common in sport activities while muscle fatigue caused by time-limited submaximal isometric tasks is more common in labor activities. In this way, the results of these different experiments lead to different applicabilities.

Acknowledgments: This study was supported by grants-in-aid from the Foundation for Research Support of the State of Bahia (FAPESB) (Award Number SUS 0055/2013) to acquire the piezoelectric platform and (Award Number JCB0056/2013) to acquire the force transducer and EMG equipment. The funder had no role in the design of the study, the collection and analysis of the data, the decision to publish, or the preparation of the manuscript. José Alberto dos Santos Rocha, Uanderson Silva Pirôpo, Rafael da Silva Passos, David Lomanto Couto would like to thank FAPESB for the scholarships granted. Alice Miranda dos Santos and Ana Maria Barbosa Argolo would like to thank Brazil's National Research Council (CNPq) and the State University of Southwest Bahia (UESB) for the scholarships granted. Authors would like to thank Edvar Pereira Nascimento Júnior, Jonas R. Dias da Silva, Murilo Carneiro Macedo and Verônica Porto de Freitas for the technical support in data collection and analysis.

Author Contributions: Uanderson Silva Pirôpo: data collection; statistical analysis; data interpretation; literature search and manuscript preparation; José Alberto dos Santos Rocha, Rafael da Silva Passos, David Lomanto Couto, Alice Miranda dos Santos, Ana Maria Barbosa Argolo and Helder Brito Andrade: data collection; data interpretation; literature search and manuscript preparation; Cezar Augusto Casotti: study design; manuscript preparation; funds collection; Rafael Pereira: study design; data collection; statistical analysis; data interpretation; literature search, manuscript preparation, funds collection.

Conflicts of Interest: The authors declare no conflict of interest.

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