31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

Effects of Maximal Oxygen Uptake Test and Prolonged Cycle Ergometer Exercise on Sway Density Plot of Postural Control

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***Abstract*—This work aims at testing the influence of the maximal oxygen uptake test and prolonged cycle ergometer exercise on sway density plot (SDP) parameters of postural control. Sixteen healthy male subjects were submitted to stabilometric tests with eye open and closed, before and after two different exercises. The maximal oxygen uptake test caused decrease of the mean duration of peaks in SDP, decreasing the stability level, without modify the rates of central and muscular torque controls. Conversely, 60 min exercise increased the mean time interval between two consecutive peaks in SDP, thus decreasing the control rate but not changing the stability level. Visual privation had a greater effect on body sway than these exercises, which were applied to muscles that are not the main actuators in body sway control. Concluding, the changes in postural control are dependent on the intensity and duration of exercise.**

I. Introduction

When a subject stays in quiet standing, his body shows spontaneous sway that can be monitored by stabilometry. The center of pressure (COP) is the measured variable, which is the resultant pressure applied over platform by the feet. The COP dynamic represents the effects of the central control, in response to afferent information from visual, proprioceptive and vestibular systems. Therefore, several models were proposed to represent the dynamic of the quiet standing control [1]-[4].

Recently, Baratto *et al.* [5] proposed a model to understand stabilograms. Three groups of subjects (normal, Parkinsonian, and osteoporotic) were used to evaluate this model, where global parameters at time and frequency domain, and structural parameters were studied. The structural parameters are based on diffusion diagram and sway density plots (SDP), proposed by Collins and De Luca [6] and Baratto *et al.* [5], respectively. The discriminative power of each parameter was evaluated according to the visual condition (eyes open and closed) and pathology effect. As result, four parameters were suggested as valuable in the clinical practice, where two were extracted from SDP: mean duration of peaks and mean interpeak distance.

This study was partially supported by the Brazilian Research Council (CNPq), José Bonifácio University Foundation (FUJB) and CAPES Foundation.

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The SDP attempt to recognize anticipatory control actions in COP signals, by identifying data clusters in this signal and interpreting them as points in which the anticipatory command is stable [5]. Particularly, SDP is constructed by counting the number of consecutive samples of the COP trajectory that appears inside a circle of a given radius. Jacono *et al.* [7] considered SDP as a robust method, since it presents low sensitivity to the influence of radius of the circle. A typical SDP shows sequences of peaks and valleys. The peaks correspond to time instants at which ankle torque and associated motor commands are relatively stable, while valleys correspond to time instants at which ankle torque rapidly shifts from one stable value to another [5]. Thus, either pathological or experimental changes, as visual condition or muscle fatigue, are expected to affect the balance control and, thus, the model parameters.

The pioneering evidences about quiet standing point out the triceps surae muscle as the most important postural muscle [8]-[10]. Therefore, the fatigue of this muscle significantly decreases the quiet standing control at bi- [11], and unipodal position [12]. Nardone *et al.* [13] showed that cycle ergometer exercises do not increase body sways even after exercise intensities above anaerobic threshold. Since the quadriceps is the main muscle involved in cycle ergometer exercises, this findings suggest that this muscle is not important in quiet standing control [14]-[15]. However, the physiological disturbances caused by maximal or prolonged exercise can decrease the neurotransmission [16] or cause central fatigue, independently of the muscular group studied [17].

The purpose of this work was testing if the SDP parameters are affected by exercises in two different protocols: the maximal oxygen uptake test and prolonged cycle ergometer exercise.

II. Materials and Methods

A. Subjects

Sixteen healthy male subjects participated in this study, with age 20-32 years, body mass 72.3 ± 11.6 kg (mean ± standard deviation) and height 1.73 ± 0.10 m. All subjects were undergraduate students in Physical Education, presented good physical conditioning, and avoided any kind of exercise during the 24 h prior to the experiments. After written informed consent, subjects were submitted to protocol previously approved by the Local Research Ethics

978-1-4244-3296-7/09/$25.00 ©2009 IEEE

Committee [approval CAAE – 0013.0.197.000-05].

B. Instrumentation

The instrumentation consisted of a vertical force platform AccuSway Balance Clinic (AMTI, USA), a mechanically braked cycle ergometer (Monark, Sweden), and an analyzer of ventilatory gas exchange VO2000 (Medgraphics, USA). The force platform was calibrated before each stabilometric trial and data was sampled in 100 Hz. A medium flow pneumotachograph was employed, with range 10 to 120 L/min, and O_2 and CO_2 sensors were calibrated before each test, by a gas with fractions of 12% for O_2 and 5% for CO_2. The sensors showed errors below 1%.

All data analysis was performed off-line using programs in Matlab, version 6.5 (The Mathworks, USA).

C. Balance Assessment

Stabilometric tests were executed in two different days. At the beginning of each session, just after calibration, subjects stood on the force platform, with the feet comfortably together and the arms relaxed by their sides. They performed five control trials with eyes open (EO), looking at a target placed at 50 cm ahead at eye level, intercalated by five trials with eyes closed (EC). A period of 10 s resting on sitting position was introduced between the 50 s trials. Thus, a total time of about 10 min was taken to perform the series of 10 trials. After this test, subjects performed exercises on cycle ergometer and thus repeated the stabilometric test. This protocol was similar to the one used by Nardone *et al.* [13]. In the first day, each subject performed a single maximal oxygen uptake test until exhaustion, with cadence 50 rpm, starting at a power output of 12.5 W, with 12.5 W/min work increments. The software Aerograph (Medgraphics, USA) computed the parameters $\dot{V}O_2$, $\dot{V}CO_2$, and $\dot{V}E$, allowing identifying the first ventilatory threshold (VT1) by v-slope method [18]. The second session was performed with minimum interval of 72 h, when each subject was submitted to the same stabilometric trials before and after a moderated and prolonged cycle ergometer exercise, with the effort set on 70% of the VT1, with a cadence of 50 rpm for 60 min.

D. Sway Density Plot

To avoid the initial transient stabilometric signals lasting about 20 s [19], only the last 30 s of the each trial were considered in the analysis. After mean removal and detrend, stabilograms referring to each one of eight conditions (before and after the two exercises, either with EO and EC) were analyzed by SDP. For each condition, the five stabilograms were initially filtered in direct and reverse direction by a low-pass Butterworth filter, 2^{nd} order and cutoff frequency 12.5 Hz. Resulting signals were decimated to 50 Hz and used in sway density curve (SDC) calculation. Each sample of the SDC was obtained by counting consecutive samples of stabilograms that remain inside a circle with radius 2.5 mm, in each time instant. Then, the time series of SDC were filtered by a low-pass Butterworth filter, 4^{th} order and cutoff frequency 2.5 Hz. These signals were multiplied by the sampling period. Therefore, SDC signals represent time series of the elapsed time by COP inside circle with radius 2.5 mm. Three parameters were extracted from each SDC: mean duration of peaks (MP); mean time interval between two consecutive peaks (MT); mean distance between two consecutive peaks (MD). The average parameters of the five trials were calculated for each one of the eight conditions.

E. Statistical Analysis

Since data could not be represented by a Gaussian probability density function (Kolmogorov-Smirnov, $p < 0.01$), Wilcoxon test was employed to compare between before and after exercise, and visual conditions ($\alpha = 0.05$).

III. Results

The SDC showed alternated peaks and valleys, as expected (Fig. 1).

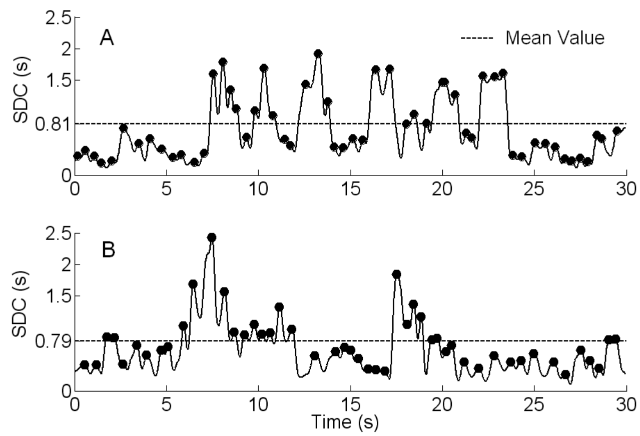

Fig. 1 Typical example of sway density curve obtained before (A), and after (B) maximal oxygen uptake test with eyes closed. Peaks (●) represent stability moments and the valleys between peaks show shifts in the center of pressure due to control commands. The mean duration of peaks (seconds inside circles) is smaller in B (0.79 s) than A (0.81 s).

The maximal oxygen uptake test caused a significant decrease in MP, both with EO ($p = 0.0494$) and EC ($p = 0.0112$) (Table I). After prolonged exercise, MT significantly increased with EO ($p = 0.0112$) and EC ($p = 0.0494$) (Table II). The EC condition significantly changed all parameters, except for MT after prolonged exercise ($p = 0.1961$) (Table I-III). MT showed higher p values, which indicates its stability.

IV. Discussion

Nardone *et al.* [13] showed increases in COP area and sway path when the exercise was performed on treadmill and above anaerobic threshold, which were not observed with cycle ergometer. These differences could be explained by the deterioration of the visual feedback caused by treadmill exercise [20]. In the present study, the SDC parameters were sensitive to cycle ergometer exercises, however the observed changes were smaller than changes caused by EC condition.

TABLE I

MEAN DURATION OF PEAKS (MP) OBTAINED BY SWAY DENSITY CURVE

	MP (s)			
	EO		EC	
	Before	After	Before	After
Maximal Oxygen Uptake Test	1.08 ± 0.16	1.01 ± 0.18*	0.70 ± 0.16†	0.63 ± 0.13*†
Prolonged Exercise	1.08 ± 0.21	1.03 ± 0.20	0.68 ± 0.15†	0.70 ± 0.15†

*Significant difference between before and after exercise ($p < 0.05$).
†Significant difference between visual conditions ($p < 0.05$).

TABLE II

MEAN TIME INTERVAL BETWEEN TWO CONSECUTIVE PEAKS (MT) OBTAINED BY SWAY DENSITY CURVE

	MT (s)			
	EO		EC	
	Before	After	Before	After
Maximal Oxygen Uptake Test	0.582 ± 0.022	0.579 ± 0.020	0.599 ± 0.020†	0.603 ± 0.016†
Prolonged Exercise	0.584 ± 0.020	0.597 ± 0.022*	0.597 ± 0.014†	0.608 ± 0.024*

*Significant difference between before and after exercise ($p < 0.05$).
†Significant difference between visual conditions ($p < 0.05$).

TABLE III

MEAN DISTANCE BETWEEN TWO CONSECUTIVE PEAKS (MD) OBTAINED BY SWAY DENSITY CURVE

	MD (s)			
	EO		EC	
	Before	After	Before	After
Maximal Oxygen Uptake Test	3.62 ± 0.50	3.73 ± 0.58	6.21 ± 1.57†	6.70 ± 1.34†
Prolonged Exercise	3.79 ± 0.79	4.03 ± 0.74	6.27 ± 1.36†	6.36 ± 1.47†

†Significant difference between visual conditions ($p < 0.05$).

The present study also used exercise protocols that were different of Nardone *et al.* [13]. Whereas those authors performed submaximal tests (25 min) with intensities above anaerobic threshold, in the present work the maximal oxygen uptake test assured that subjects reached the maximal intensities. Even at submaximal load, in present study the exercises lasted for 60 min, whilst in Nardone *et al.* [13] subjects pedaled just for 25 min.

Further, Nardone *et al.* [21] confirmed that treadmill exercises increase area and sway path for about 15 min. Thus, the present protocol followed Nardone *et al.* [13] and Nardone *et al.* [21] recommendations, since the stabilometric trials after exercise started almost immediately after it, and lasted about 10 min. Therefore, stabilometric measurements were performed before full recovery after effort.

According to Skinner *et al.* [22], fatigue causes negative effects on proprioception because decreases the activation of muscular mechanoreceptors and the muscular strength. Additionally, Forestier *et al.* [23] showed that tibialis anterior and triceps surae fatigues decrease ankle proprioception. These findings corroborate previous results that triceps surae fatigue increases postural instability [11]-[12]. In spite of that, Adlerton and Moritz [24] performed an experiment at which the fatigue was induced in triceps surae and mean velocity of COP did not show significant increase, even on unipodal position. Fatigue was induced by unilateral plantar flexions with maximal repetitions until failure. The authors argued that compensatory mechanisms could be evidenced when the muscle fatigue occurs, and one proposed mechanism was the increase of the muscle spindle reflex activity. This does not agree with Loram *et al.* [25], which showed that in quiet standing, triceps surae spindles do not participate in body sway control because this muscular group does not stretch with the imminence of forward fall. Therefore, a reasonable explanation for the difference between these results is the type of contraction performed. Whilst Mello *et al.* [11] and Vuillerme *et al.* [12] used isometric contractions, Adlerton and Moritz [24] used isokinetic contractions.

In the present study, only concentric contractions of the quadriceps muscle were performed, and these contractions are expected to cause a smaller proprioceptive disturbance than eccentric contractions [26]. Consequently, the cycle ergometer exercise only generated alterations in one parameter of the SDC in each kind of exercise: MP reduced after maximal oxygen uptake test, while MT increased after prolonged exercise. Conversely, the change in visual condition caused notable changes in all parameters.

The greater effect of visual privation on SDC parameters than exercise is in accordance with Nardone *et al*. [13]. The results of the present work corroborate the dominance of visual feedback over proprioception [27]. Vuillerme *et al*. [12] showed that visual afference can attenuate fatigue effects, thus supporting the hypothesis that the importance of the visual information increases when other afference is harmed [28].

The three parameters extracted of the SDC can be related to both anticipatory control and postural stability level [5]. Therefore, the significant decrease of the MP after maximal oxygen uptake test reflects the decreased stability level of the postural control system, due to quadriceps fatigue. The increased MT after prolonged exercise indicates decreased rate of posturographic commands, reflecting some level of central fatigue. Thus, the use of SDC allowed discriminating changes in quiet standing, even when related to the role of muscles not primarily responsible by body sway control.

V. Conclusion

The changes in postural control are dependent on the intensity and duration of exercise. Maximal oxygen uptake test showed decrease only in MP parameter, indicating that maximal anaerobic exercise causes decreased stability level, without modifying the rates of central and muscular torque controls. After prolonged exercise, conversely, only MT increases, thus indicating that prolonged aerobic effort causes decreased control rate, without changing the stability level.

Visual privation had a greater effect on body sway with the type of contraction and the muscular group studied in this protocol.

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