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Analysis of Postural Control in Elderly on Horizontal and Inclined Surfaces Using Classical Descriptors and DFA

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Abstract— **Understanding how the postural control system is impaired with aging can help identify elderly at risk of falling. In order to study the postural control, center of pressure (COP) behavior can be analyzed. The objective of this study was to evaluate the capacity of Detrended Fluctuation Analysis (DFA) to discriminate the postural control of elderly in horizontal and inclined (14 degrees) surfaces, with and without visual input, comparing the results with the ones obtained with the classical variables, like mean velocity and total COP displacement. Results with classical variables revealed significant differences in all comparisons realized, but DFA was not able to classify the differences between conditions. It is suggested further studies to verify the efficiency of DFA in physiologically different groups, like subjects with some pathology that affects the balance or the ones wearing a robotic prosthesis from healthy subjects, in which it seems to have a greater sensitivity.**

I. Introduction

The postural control system is responsible for maintaining the human body balance, and involves the integration of sensorial and motor functions of the nervous systems. Postural control may be studied evaluating the behavior of body sway during quiet static standing. One technique used to evaluate the body sway or a variable associated with it is the posturography, in which the most commonly used measure to evaluate the posture control is the center of pressure (COP) [1]. COP measures can be used to investigate the degradation of the postural control system related to aging or balance disorders [2] and can also be used to investigate the difficulty to maintain balance reported by other subjects, such as the prosthetized ones [3].

Studying the postural stability of elderly can provide useful information about their postural control system, which is impaired with aging, and may help identify elderly with an increased risk of fall [4]. One factor that requires attention, especially in the elderly, is the transposition of surfaces at different levels like ramps, steps and stairs, because this activity demands greater efforts than those observed on horizontal surfaces [5]. Therefore, it is expected that the mechanisms of postural control in elderly subjects on inclined surfaces are less effective than on horizontal ones, making them more susceptible to falls. There are physiological differences when the subject is on an inclined or on a horizontal surface due to the responses from the upper motor centers to the proprioceptive inputs, that expose both flexors and extensors ankle muscle spindles to different lengths. Inclined surfaces alter these proprioceptive inputs [6].

Proprioceptive inputs will also be different in subjects wearing some type of prosthesis. Lately, several types of prosthesis are being developed, such as robotic exoskeleton or active prosthesis. These devices can provide better assistance to people with some kind of disability, making it easier to walk or stand mimicking a real limb. Although such devices are being developed rapidly, no much attention is given to how users interact with exoskeletons [7]. Understand the physiological responses on healthy subjects can help develop more accurate control systems for prosthetic devices.

Using posturography in a clinical context is not new, but there is no agreement regarding methods, techniques and interpretation of the data [8] . New analytical techniques have been developed, aiming to go beyond the characterization of the raw properties of postural sway. It is expected that these methods can provide more information about the processes underlying the control and reveal the significant structures responsible for the spontaneous fluctuations of posture that occur in the absence of external perturbations [9]. One of these techniques is known as Detrended Fluctuation Analysis (DFA) introduced by Peng and colleagues [10]. DFA calculates a scale exponent, which can provide information on the correlation properties of the signal, revealing the presence of long-range correlations even when the time series is apparently non-stationary [11]. This type of measure, unlike traditional ones, may help to understand the physiological mechanisms that may be responsible for degradation of postural control in elderly [12].

To our knowledge, there is no previous studies using DFA to compare the postural control of elderly in different surface inclinations. Investigate whether the DFA can identify the changes that occur in postural control in this population, on inclined and on horizontal surfaces, can contribute to the construction of the clinical parameters to observe the different physiological responses of the subject, in order to identify whether the analysis with the DFA is accurate for testing the stability, and use it as measure in future tests, like, for instance, verifying if a robotic leg is mimicking a real one, in a prosthetic elderly subject.

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In order to contribute to researchers and clinicians who use COP based measures to assess postural stability, the objective of this study was to verify the ability of DFA to discriminate differences in postural control in elderly on horizontal and inclined surfaces with and without visual information, comparing the results with the ones obtained by analyzing classical variables, that are widely used in the literature to investigate the postural control [1],[13],[14].

II. Methods

A. Sample/Population

The sample consisted of 10 elderly patients, 8 women and 2 men. Subjects were selected within a group assisted by the health care program Estratégia de Saúde da Família (ESF) at Professor Jamil city - Goiás. Inclusion criteria was: age equal or greater to 60 years. Exclusion criteria were the presence of the following aspects: cognitive impairment that prevented understanding the guidelines given by the researcher, motor impairment or use of assistive device to maintain upright posture or gait and have a diagnosis of a disabling illness.

The study was approved by the Committee on Ethics in Research of Universidade Federal de Goiás. All participants were informed about the research procedures and signed a consent term.

B. Instruments

Two force platforms (Accusway, AMTI) were used for data acquisition. Data were acquired at a sampling frequency of 100 Hz and filtered by a low-pass, fourth order, zero-lag phase *Butterworth* filter with cutoff frequency set as 12 Hz.

C. Procedures

Participants remained in the orthostatic posture, on a force platform for 60s during each trial, with self-selected spacing between feet. Data acquisition was performed with one platform on a horizontal surface and another platform on an inclined surface at 14 degrees (ankle dorsiflexion) according to Mezzarane and Kohn [6]. For each inclined situation, they performed three trials with eyes open (EO) and three trials with eyes closed (EC).

D. Data analysis

COP displacements were analyzed in anteroposterior (AP) and mediolateral (ML) direction in a projection of the force platform on the floor [6]. Some classical methods to analyze the data were used in the time and in the frequency domain and we also analyze them using DFA. Classical variables were: resulting sway displacement (DTOT), which is the length of the COP trajectory on the support base; mean velocity (VEL) in each direction (AP, ML), that indicates how fast the COP displacements were; area of the COP ellipse, calculated using a method to estimate the area of confidence of the COP trajectory on the force platform [15], in this case, 95% of the COP data and mean frequency (Fmean) that was obtained from the frequency spectrum estimated through the Fourier Transform, using the *Welch* method, *Hanning* window with 2000 samples and 50% of superposition, that gives 0.05 Hz of resolution [6],[16].

Detrended Fluctuations Analysis estimates a scale exponent α which can describe the nature of the time series. The time series of COP displacements, d_{cop}, is divided in sampling intervals τ. For each interval, are calculated the mean value of $d_{cop\tau}$, a function *y(n)* and a linear model *z(n)* (1-3), where *a* and *b* are the angular and linear coefficients of the linear model, obtained using the least square fit of the respective interval, and *n* is the current sample.

$$d_{cop_\tau} = \frac{1}{\tau}\sum_{i=1}^{\tau} d_{cop}(i) \quad (1)$$

$$y(n) = \sum_{i=1}^{n} \left(d_{cop}(i) - d_{cop_\tau}\right) \quad (2)$$

$$z(n) = an + b \quad (3)$$

A fluctuation function *FF(k)* is calculated for each interval *k* (4), where $1 \le k \le N/\tau$, and *N* is the total number of samples, than *FF(k)* is estimated for each interval (5).

$$FF(k) = \sqrt{\frac{1}{\tau}\sum_{n=(k-1)\tau+1}^{k\tau} \left|y(n) - z(n)\right|^2} \quad (4)$$

$$F(\tau) = \frac{1}{N/\tau}\sum_{k=1}^{N/\tau} FF(k) \quad (5)$$

It is expected a behavior like $F(\tau) \approx \tau^{\alpha}$, where a characteristic exponent α can be extracted from the slope of line of the $log(F(\tau))$ *vs* $log(\tau)$ graph, defining whether the signal is persistent, anti-persistent or a white noise [6]. An exponent $\alpha = 0.5$ classifies the time series as random and non-correlated (white noise), when $\alpha < 0.5$, the signal presents negative correlations (anti-persistent) and if $\alpha > 0.5$, there are positive correlations (persistent) [17].

The variables were calculated using scripts written in MATLAB environment. For statistical analysis, we used the SPSS (*Statistical Package for Social Sciences*). Normality was tested using the *Shapiro-Wilk* test. To compare the results obtained on horizontal and inclined surface *t-Student* test for paired samples was performed. The significance level was set as ≤ 0.05.

III. Results

Results are expressed as mean and standard deviation (mean ± SD). Mean age was 69.30 ± 4.11 years; weight, 69.40 ± 15.21 kg and height 1.52 ± 8.2 m.

Table I shows the results obtained comparing EO and EC in each surface. All classical variables had significant differences in this case ($p \le 0.05$). DFA had significant difference between EO and EC only when analyzing COP in the AP direction over an inclined surface.

Table II shows the comparison between surface condition (horizontal and inclined). For EO, statistical difference was found only for the variables VEL_AP, Fmean and DTOT. Results for EC revealed significant differences in VEL_AP, VEL_ML, Fmean and DTOT variables. DFA had similar scale exponents between the two surfaces with no statistical differences.

IV. Discussion

This study aimed to verify the ability of DFA to discriminate differences in postural control of elderly in two different surfaces: horizontal and inclined at 14 degrees. The hypothesis that elderly have less efficient mechanisms of

TABLE I. COMPARISON BETWEEN EO AND EC IN BOTH INCLINATION CONDITIONS

	Horizontal surface			Inclined surface		
	EO	***EC***	***P***	***EO***	***EC***	***P***
AREA (cm^2)	1.79 ± 0.92	2.25 ± 1.27	0.027^+	2.05 ± 1.45	2.89 ± 1.58	0.010*
VEL_AP (m/s)	0.76 ± 0.24	1.08 ± 0.43	0.003^+	1.00 ± 0.21	1.41 ± 0.48	0.006*
VEL_ML (m/s)	0.45 ± 0.15	0.51 ± 0.16	0.004^+	0.56 ± 0.19	0.72 ± 0.32	0.007*
DTOT (cm^2)	58.20 ± 16.19	77.61 ± 27.27	0.002^+	75.95 ± 15.51	103.98 ± 30.53	0.002*
Fmean (Hz)	0.29 ± 0.12	0.35 ± 0.12	0.037^+	0.36 ± 0.14	0.43 ± 0.17	0.007*
DFA_AP	1.03 ± 0.11	0.94 ± 0.13	0.080	1.06 ± 0.07	0.91 ± 0.10	0.002*
DFA_ML	1.01 ± 0.15	1.11 ± 0.20	0.152	1.07 ± 0.26	1.04 ± 0.17	0.626

Results are expressed as mean ± SD. EO – Eyes Open, EC – Eyes Closed $^+$ = $p < 0.05$, EO and EC compared on horizontal surface; * = $p < 0.05$, EO and EC compared on inclined surface

TABLE II. COMPARISON BETWEEN INCLINATION CONDITIONS

	Eyes open			Eyes Closed		
	Horizontal	***Inclined***	***P***	***Horizontal***	***Inclined***	***P***
AREA (cm^2)	1.79 ± 0.92	2.05 ± 1.45	0. 382	2.25 ± 1.27	2.89 ± 1.58	0. 198
VEL_AP (m/s)	0.76 ± 0.24	1.00 ± 0.21	0.022^+	1.08 ± 0.43	1.41 ± 0.48	0.010*
VEL_ML (m/s)	0.45 ± 0.15	0.56 ± 0.19	0.077	0.51 ± 0.16	0.72 ± 0.32	0.050*
DTOT (cm^2)	58.20 ± 16.19	75.95 ± 15.51	0.024*	77.61 ± 27.27	103.98 ± 30.53	0. 007*
Fmean (Hz)	0.29 ± 0.12	0.36 ± 0.14	0.023*	0.35 ± 0.12	0.43 ± 0.17	0. 049*
DFA_AP	1.03 ± 0.11	1.06 ± 0.07	0.507	0.94 ± 0.13	0.91 ± 0.10	0. 697
DFA_ML	1.01 ± 0.15	1.07 ± 0.26	0.607	1.11 ± 0.20	1.04 ± 0.17	0. 374

Results are expressed as mean ± SD. EO – Eyes Open, EC – Eyes Closed; $^+$ = $p < 0.05$, comparison between horizontal and inclined with eyes open; * = $p < 0.05$, comparison between horizontal and inclined with eyes closed.

postural control on inclined surfaces compared to horizontal ones was tested.

A. Classical analysis

Significant differences between EO and EC found in the analysis of classical variables are reported in the literature. COP trajectories tend to increase with the decrease of sensory information, indicating that the control of posture is performed less effectively when the subject is deprived of visual information [13]. Prieto and colleagues [4] evaluated the postural stability of elderly and compared them with young subjects, and reported that, when comparing EO and EC, the mean COP velocity of elderly subjects was higher with EC, which agrees with the present study (Table I). The mean COP velocity has been quantitatively related with the regulatory activity associated with efficacy or stability achieved by the postural control system. When analyzing the differences in postural control in healthy young subjects at different inclinations using the power spectral density, Mezzarane and Kohn [6] found significant differences in all conditions evaluated when analyzing the vision effects, including on horizontal and inclined at 14 degrees surfaces, stating that this type of slope is highly dependent on vision, which is in agreement with the present study.

According to Cavalheiro and colleagues [16], many traditional variables provide similar information because they are highly correlated with each other, however, they may differ in the fact that some are able to discriminate groups or not, in their case, evaluate the differences between a group of healthy young and a group of elderly. In our study, just some variables showed significant differences between the inclination conditions, presenting higher values for the 14 degrees inclination. Higher values for the classical COP variables may indicate a reduction of postural control mechanisms [14]. Mezzarane and Kohn [6] found different spectral characteristics between a posture on horizontal surface that on inclined surfaces. They suggested that these differences could be related to alterations in sensory inputs. Another factor that could potentially contribute to these differences is the biomechanical constraints arising from inclined surface activities. In our study we obtained similar results, since in the inclined surface there was an increase in the mean frequency calculated from the power spectrum (Table II).

Mean COP velocity and total displacement can quantify the relationship between the activity of the postural control system and stability achieved by the subject [4]. In this study, these variables showed statistical differences when comparing the slope conditions (see Table II), and the total displacement was the variable that increased the most when the subject was in an inclined surface.

B. DFA

DFA scale exponents for all conditions were $\alpha > 0.5$, indicating long-term correlations. Using DFA and comparing the results between EO and EC in each inclination, no significant difference was observed in the AP and ML directions, which agrees with some studies [11],[18] that affirm that the DFA may not be able to elucidate the effect of visual information indicating that the absence of this information cannot modify the scale properties provided by DFA. Considering different inclinations, the DFA in AP direction showed statistical difference ($p = 0.002$) between the horizontal and inclined surface, however, the exponent of both conditions classified the signal in the same category ($\alpha > 0.5$).

The results using DFA are controversial. Cavalheiro and colleagues [16] used DFA to analyze different groups (young and healthy elderly subjects) and found no significant differences between them. This result suggests that DFA may not be sensitive to discriminate certain groups. However, Amoud and colleagues [12] performed a study with a similar group (young and healthy elderly) and identified differences in postural stability between them using DFA. In our study, DFA was also not able show significant differences between the two inclinations analyzed.

Blázquez and colleagues [18] compared the DFA results obtained in adults, with mean age 41 ±11 years, with their previous studies with a similar population and found similar exponents for AP and ML directions ($\alpha \sim 1.0$). This result is in accordance with ours, in which all values found for the DFA scale exponents in the AP and ML direction for both surface conditions showed $\alpha \sim 1.0$. This may be indicative of smoother signals with high correlation. α values greater than 0.5 indicate persistent time series with a lower variability [12]. However, Cavalheiro and colleagues [16], compared DFA results from young and elderly subjects and found scale exponents close to 1.5 for both groups, characterizing COP signals as Brownian movements.

DFA is considered a powerful method to study the dynamical properties of COP [11] and may provide information regarding the physiological processes related to postural control, since it extracts information regarding the strategies used on the underlying control that regulate the posture stability. Simple statistical parameters extracted from posturographic analysis, like area and the total COP displacement, are tools that have been able to identify individuals at potential risk of falling, however, these parameters provide little knowledge about the underlying mechanisms of control involved in the age-related degradation of balance [12]. In the present study, classical variables were able to differentiate all the proposed conditions, but DFA classified all signals into the same category.

V. Conclusion

The results of this study show that despite DFA is considered an effective method to analyze the COP displacements physiologically, it may not have the same efficiency to differentiate groups in different protocols conditions, thus using more tools, in this context, as mean velocity, total displacement, mean frequency that are able distinguish groups, is necessary. Therefore, we suggest further studies using DFA to verify its ability to discriminate physiologically different groups, like subjects with some pathology that affects balance or the ones wearing a robotic prosthesis from healthy subjects.

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