pHealth 2020
B. Blobel et al. (Eds.)

doi:10.3233/SHTI200639

Evaluation of Postural Stability Differences in the Elderly Through Recurrent Analysis

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Abstract. Measuring the center of pressure (CoP) for a subject positioned on a force plate is one of the most commonly used tools to investigate balance. Several studies have proven a significant degradation of the body's stability after the age of 60. The conclusions, however, are based on a limited number of indicators and without systematic nonlinear analysis methods being used to evaluate the progression of CoP parameter values. Neither the change in CoP movement in subjects over 60 years of age nor the considerations of their body mass index (BMI) has been systematically evaluated by nonlinear methods so far. This study is based on one of the frequent methods for nonlinear evaluation - the Recurrent Quantification analysis. This article discusses the applicability of this method with regards to the evaluation of changes in postural stability of subjects over 60 years of age. Postural stability changes were evaluated using CoP motion and tested by the nonlinear method. For this research purpose, a group of 103 elderly women were selected and divided into age-respective groups of 60–69 years and 70–79 years old. Each age group was further divided into a subgroup of normal and overweight subjects according to their BMI. The following recurrent analysis parameters were employed in the evaluation of CoP motion in medial-lateral and anterior-posterior directions: determinism (DET), laminarity (LAM) and trapping time (TT). The results of the Wilcoxon test revealed a statistically significant difference between the values in parameters for the different age groups of overweight subjects almost in all the cases. Conversely, statistically significant differences between age groups rarely occurred in a subgroup of subjects with a normal BMI.

Keywords. Center of pressure, Postural stability, Recurrent analysis, Nonlinear method, Elderly, Age, Body mass index.

Introduction

Measuring the center of pressure (CoP) of a subject positioned on a force plate is one of the most commonly used tools to investigate a balance [1]. Several studies prove a significant degradation of the body's stability after the age of 60 [2, 3]. Their conclusions, however, illustrate that evaluation was just based on the basic methods of statistical and linear analyses [4] but promising methods of nonlinear analysis [5, 6], have not been

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systematically used to assess postural stability of the elderly. Moreover, in the majority of studies, the change in stability related to body mass and body height in very old age groups, has not been taken into consideration. Only a few studies have addressed the application of more complex CoP methods assessing movement for the monitoring changes in parameter values with respect to people over the age of 60 [7].

Based on the above and eliminating the drawbacks of linear methods for evaluating CoP motion while a subjects is standing on force platform, this article aims to verify the applicability of a representative nonlinear methods, such as the Recurrent Quantification analysis [8]. Recurrent analysis was selected as it can be presented graphically and has already been used experimentally in similar cases [9]. This article also presents the applicability of the method for the evaluation of changes in postural stability of females aged 60 and above in relation to changes in CoP movement and the influence of a different body mass index.

1. Methods

1.1 Participants

The observed group of healthy subjects consisted of 54 women aged 60–69 and 49 women aged 70–79. The symptomatic assessment involved a comprehensive medical history and regular laboratory testing. The data was obtained within a larger research protocol [7]. The study protocol was approved by the local Ethics Committee of the Palacky University Olomouc. The subjects were measured on different days [10]. Based on the biometric data of each subject, a body mass index was determined [11].

1.2 Measurement Equipment

A force plate AMTI (Advanced Mechanical Technology, Inc., Watertown, USA) model OR6-5 was used for CoP recording providing information on CoP coordinates (ML - mediolateral, AP - anteroposterior). An Airex Balance Pad (Airex AG, Sins, Switzerland) is a soft, smooth, flat mat designed for balance training when standing barefoot and for this research purposes was used as a supplement impairing perception. Due to the foam material, a person standing on the mat was constantly forced to stabilize their joints and balance, [12]. The output signal was not filtered in order to preserve the ability to identify errors during final evaluation.

1.3 Measuring procedure

The CoP coordinates were measured while the subjects were standing with eyes open (EO) on a firm surface (FiS) and eyes closed (EC) on a soft foam surface (FoS). The coordinates of CoP behavior were measured for 30 seconds of standing still under the three following conditions: 1. firm surface and closed eyes (FiS EC); 2. foam surface and open eyes (FoS EO); and 3. foam surface and closed eyes (FoS EC)), [4]. These two commonly used test types were chosen as they are able to determine the difference between non-reduced visual perception and mechanoreceptor perception and between maximum reduction of the visual perception and mechanoreceptor perception, [12].

While a subject was standing, a visual target was positioned at their eye level, at a distance of approximately 1.5 metres.

1.4 Data Processing

Recurrence is a fundamental property of dynamic systems, which can help characterize the system's behavior in phase space. A recurrence plot, a powerful tool for result visualization and analysis, was introduced in the late 1980's, [13], [14]. The algorithms in accordance with, [13], [14], are applied in a custom-written software for graphical presentation and calculation of CoP parameters, see Fig.1.

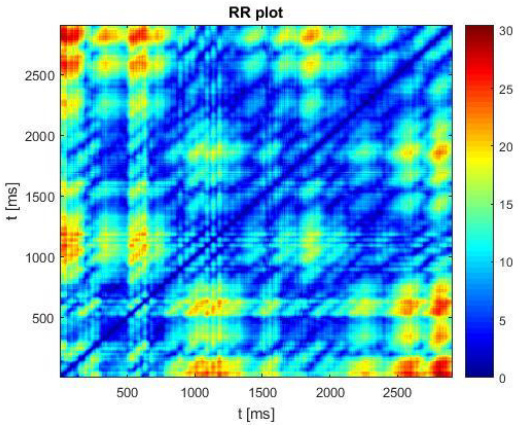

Figure 1. Example of graphical output used for calculation of recurrent analysis parameters

The calculated parameters of recurrent analysis, employed in the evaluation of the CoP movement are:

- Determinism (DET), which quantifies the relative ratio of diagonal elements to other components in a recurrence matrix, indicating the overall periodic content of a given signal, [15], is described in detail in [16],
- Laminarity (LAM), which quantifies the ratio of recurrence points belonging to laminar structures against the total frequency of recurrence points, and therefore is considered an overall measure of signal stability, [13], is described in detail in [15],
- Trapping time (TT), which describes the mean length of laminar (vertical/horizontal) structures, and is analogous to how mean diagonal length captures periodic durations, [13], is described in detail in [15].

1.5 Statistical analysis

Recurrence analysis results were evaluated by standard statistical evaluation methods. After calculating the DET, LAM and TT of each subject, a normality Shapiro-Wilk test was conducted. Since the normal data distribution did not appear, statistical evaluation was carried out by non-parametric tests. The Wilcoxon rank sum test assessed the significance of the differences between the results. The significance level was set at 5% (i.e. p=0.05). Statistical analysis of data was performed in MatLab software (MatLab R2010b, Mathworks, Inc., Natick, MA, USA).

2. Results

The results measured in individual groups were then compared. The findings showed a statistically significant difference between the parameter values in different age groups of overweight subjects almost in all cases, i.e. in both movement direction under both conditions. In contrast however, subjects with a normal BMI, rarely produced statistically significant differences between age groups. Table 1 shows p-values of the age group comparisons.

Table 1. Comparison of parameter values for different age groups of subjects.

Measurement conditions	BMI	Direction of movement	DET	LAM	TT
FiS EC	normal	AP	0.57	**0.01***	0.11
		ML	0.31	0.11	0.09
	overweight	AP	**0.05***	**< 0.01***	**0.02***
		ML	**< 0.01***	**< 0.01***	**< 0.01***
FoS EC	normal	AP	0.71	0.84	0.55
		ML	0.62	0.18	0.65
	overweight	AP	**0.03***	**< 0.01***	0.07
		ML	0.07	**< 0.01***	**< 0.01***
FoS EO	normal	AP	0.12	0.06	0.29
		ML	**0.05***	**0.01***	**0.04***
	overweight	AP	**< 0.01***	**< 0.01***	**< 0.01***
		ML	**< 0.01***	**< 0.01***	**< 0.01***

BMI: Body mass index; DET: Determinism; LAM: Laminarity; TT: Trapping time; FoS: foam surface; FiS: firm surface; EC: eyes closed; EO: eyes open; ML: medial-lateral direction; AP: anterior-posterior direction; *: significant difference.

3. Discussion

Statistically the most significant differences appeared between age groups for LAM. LAM, however shows statistically significant differences in other measurings, even where the DET and TT do not reflect differences between age groups, see Table 1. Generally said, LAM is the most sensitive factor to determine differences in CoP position between different age groups as it is fluidity of motion. This leads to the assumption that not all recurrence measurements indicate the same characteristics of CoP movement. It is also interesting that as for ML direction of CoP movement while standing on FoS with EO, a statistically significant difference was discovered in all indicators (LAM, DET and TT) in subjects with a normal BMI. The reasons may be related to the reduction in perception when standing on FoS EO. In contrast to standing position with the EC, the subject may not be trying to compensate intensively for the loss of perception, which is reflected as larger fluctuations in the CoP position. These assumptions, however, will need to be analyzed in more detail in broader clinical research.

It should be noted that none of the methods and conclusions presented in the world so far have led to these findings, and there are none of the traditional methods based on linear data analysis that would mention these conclusions. We used nonlinear measures because characterizing the complexity of time signals to detect system features (ie changes in time) that cannot be derived from linear analyzes, [17]. Only few studies have considered evaluating the postural stability of the elderly using nonlinear methods. However, the articles generally focus on subjects suffering from any of the diseases and comparisons were made with healthy subjects, [18], [19]. Of course, most nonlinear methods lead to the finding of statistically significant differences between healthy subjects and diseased subjects. However, our contribution did not focus on the application of nonlinear methods in this way. The difference between younger and older subjects was also studied. Statistical differences were also found in this case, [20]. So the findings in our article are original and unpublished and complement the results obtained by linear methods, see [7]. These findings are also important for the use of method and methodology in clinical practice.

This study adopted several limitations. Foremost, it would be necessary to perform measuring on people with specific diseases and compare the results with the results achieved by traditional methods of linear analysis. This will be a component of follow-up research. The statistical results of this preliminary research indicate important conclusions and the applicability of recurrent analysis methods for the evaluation of the CoP movement in elderly females. This study complements previous research highlighting the differences in postural stability in the aged population of men and women, [12], with the current study on the dependence of postural stability of women with different BMIs.

From an engineering point of view, it is also necessary to recommend that subsequent studies focus on testing other parameters of the recurrent quantification analysis, as well as on other methods of nonlinear analysis and the calculation of parameters, such as: largest Lyapunov coefficient, slope of curve for detrended fluctuation analysis and Poincaré plot parameters, [5], [6], [7]. The authors believe it will be interesting to see if these parameters will lead to the same conclusions.

4. Conclusion

The research conducted proved that the novel method of evaluating CoP movement in elderly people, based on the parameters of Recurrence Quantification Analysis, is able to identify differences in postural balance. It offers a crucial advantage of being able to examine the evaluation of the measured CoP variables, providing a complex image about CoP movements during measurement. This approach makes it different from the traditional linear methods which focus merely on the discrete values of CoP movement in medio-lateral and/or anterior-posterior direction. The proposed techniques, along with the stabilometric platform involved, should be viewed a contribution to the postural stability study in aged people, for whom the widely used methodology, based on nonlinear methods, has not been adopted. In this respect the Recurrence Quantification Analysis, as described in the study, is a pioneering work revealing the effect of age and BMI upon the CoP position and its change over time. The results obtained by statistical evaluation should be followed by a medical analysis of the results and their interpretation. With regard to testing and recommendations of the recurrent analysis in clinical practice,

this is as stated before, is beyond the scope of this work but could be explored further in future by others.

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