

Complex feature analysis of center of pressure signal for age-related subject classification

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ABSTRACT

Purpose: The aim of this study was to characterize prolonged standing and its effect on postural control in elderly individuals in comparison to adults.

Materials and Methods: The elderly individuals' behavior during standing and how demanding such a task is for them, is still unknown. We recorded the center of pressure (COP) position of 12 elder and 15 young participants while they were standing for 30 seconds. Then an analysis was performed to find the most appropriate and discriminative features for the elderly and young posture signals discrimination. Features were selected in frequency and time domain. Largest Lyapunov exponents of the COP signals were also computed to show the impact of chaotic behavior in static balance characterization relative to age.

Results: Working in frequency domain is preferred to time domain analysis and largest Lyapunov exponent of the posture signal can be representatively used for COP signal discrimination between the two classes of subjects.

Conclusion: In investigation and analysis of static balance for elders and unhealthy participants the signal of COP can be studied in chaotic domain beside frequency domain. Extraction of features from both chaotic and frequency domains significantly improves the discrimination rate of balance signals in age-related classes.

Keywords: static balance; center of pressure; age relation; largest Lyapunov exponent; feature extraction.

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INTRODUCTION

Postural balance is the ability to stabilize the center of pressure (COP) for the body during a prolonged standing or walking. In our everyday life, we frequently stand for a prolonged period (more than a few minutes) while chatting to somebody, waiting in a line, or standing in a work environment, i.e. we stand in order to perform another task which in this context may be referred to as a suprapostural task.^{1,2} In such natural standing, continuous low amplitude and slow swaying of the body is commonly interrupted by postural changes characterized by fast and gross body movements.³⁻⁵ These postural changes are thought to be performed in order to diminish the discomfort caused by psychological factors (including increase of tension, mental stress, and reduction of motivation and concentration) and physiological factors

(including increase of venous pooling in the lower extremities, occlusion of blood flow, vertigo, muscular fatigue and increased joint pressure).⁴⁻⁹

Many aspects of postural control decline with age and then the postural deficits are a contributing factor to an increased likelihood for falls in many older adults.¹⁰ One third to one half of all people over the age of 65 years old fall at least once per year¹¹ and a prolonged fear of falling as a result decreases their activity levels.¹² Subsequently, decreased mobility resulting from fear or injury can cause a decline in independence.¹¹ Many studies have reported improvements in postural stability after visual biofeedback-based training of balance in elderly.¹⁶⁻¹⁸ However, the extent to which biofeedback information can improve balance has not been determined yet.

Using a magnetic-based force platform allows the

extraction of the COP's displacement of a subject, which can be used to quantify the postural stability. From this measure we deduce the stabilogram which is the representation of the COP time series in anteroposterior and mediolateral direction.¹¹ The stabilogram is known to be a nonlinear and nonstationary signal.¹⁸ So to analyze it, studies have used several decomposition methods such as wavelet approach,¹⁹ empirical mode decomposition,^{11,20,21} and compensatory postural adjustments (CPA) decomposition.²² Other studies have not decomposed the stabilogram signal but extracted specific parameters such as root mean squared (RMS), mean velocity of body sway, and mean COP amplitude to study the effect of aging on the stability.^{3,23,24}

Several types of methods are used to analyze the displacement of the COP. Some employ traditional tools such as the total displacement, mean velocity, RMS value, mean frequency and the confidence ellipse area.^{13,14,16,19,21} Others use mathematical techniques from statistical mechanics, assuming that the displacement of the COP is a random process,^{1,2,4-7,9,10,17,19,20,22} e.g. the stabilogram diffusion analysis, detrended fluctuation analysis and R/S analysis. Although it is possible to find a number of studies in this area, there is a lack of investigations that seek features computed from the displacement of the COP that may reflect changes in the postural control over the ageing. In this context investigated how traditional and recent tools can be employed to investigate the correlation of changes in the displacement of the COP over the ageing.

The aim of this study was to characterize the stability patterns in chaotic and frequency domains. Then, the affectivity of age to postural balance was studied by the extracted features analysis.

MATERIALS AND METHODS

Twenty seven healthy individuals (13 females and 14 males) participated in the stabilogram acquisition test. Information about each subject was provided, including: name, age, height, weight. The subjects' ages were between 18 and 60 years old. Their weights were between 58 and 107 Kg and their heights were between 164 and 187 cm. The subjects were divided into two groups based on age: control group (15 subjects with ages between 18 and 24 years old) and adult group (12 subjects with ages between 25 and 60 years old). All the participants were considered as normal since they had no visual impairment, anatomical and musculoskeletal disorder and no other abnormality in their static balance. Informed consent was obtained from all the participants

before their participation in the study.

Each test took 30 seconds time. Ten tests for the young and 5 tests for the elder participants were undertaken of which five 30-second tests were taken into account for each participant in our analyses.

In this study, low frequency power ratio, standard deviation of power spectrum index in high frequencies, signal standard deviation and largest Lyapunov exponents were the variables for adult-elder posture signal discrimination. Defined parameters have been separately calculated and compared for both classes of participants in both mediolateral and anteroposterior directions. All simulations have been performed by MATLAB R2010a software.

To calculate the low frequency power ratio, the signals were first normalized by the following formula,

$$S = \frac{s - M}{\delta}$$

In which S is the normalized signal, s is the original signal, M is the average and δ is the standard deviation of the original signal. After the Fourier transform was obtained, the power ratio of the signal in frequency range DC to 2/3 Hz to its total power was calculated. The reason why this parameter was used is because the body vibrations during the aging process in elders increases and therefore the power of the signal in low frequencies is decreased. This parameter can then be representatively used for comparison and posture signal discrimination between young and elder subjects.

The standard deviation of power spectrum δ_p was the second selected feature which is defined as the ratio of standard deviation of signal's power spectrum from the frequency 1 Hz to higher frequencies to standard deviation of the total power spectrum. Calculating the power spectrum is similar to the previous normalized signals.

Standard deviation of the signal δ was considered as another feature which was calculated in the following formula:

$$\delta = \sqrt{\frac{\sum (x_i - M)^2}{n}}$$

This parameter was used since by enlarging the amplitude of the vibrations, the standard deviation of the signals will probably be higher in elders compared to the young. Average of the signal M yields us the mean value over the whole signal range and this value is considered as another feature. In chaotic domain the largest Lyapunov exponent of the signal known as the representation of

the chaotic behavior of the signal as a time series is considered as a feature. The largest Lyapunov exponents of the signals are computed by the method presented by Razjouyan and colleagues.²⁵

The features of the 30-second time intervals of the signals are compared in the Tables 1 and 2. The aim was to find which of the defined parameters best describe the signal and yield us a discriminative feature usable for posture signal classification of elder and young participants.

RESULTS

First the features were compared for young and

elder participants in the fifth 30-second test in the anteroposterior direction. Table 1 shows the results for comparing the three features of standard deviation, low frequency power ratio and Lyapunov exponents for young and elder people in anteroposterior direction. These three features are also compared for the mediolateral direction in Table 2.

Figure 1 compared to Figure 2 shows higher discriminating scheme in distinguishing posture signals of elder and young subjects in anteroposterior direction. In fact, mean and standard deviation of the posture signals for the two groups in Figure 2 have high level of amalgamation and discrimination is not easily achieved.

Table 1. Standard deviation, low frequency power ratio and Lyapunov exponents (anteroposterior direction) for young and elder participants in the fifth 30-second test.

	Young Subjects			Elder Subjects		
	δ_p^*	Power Ratio	Lyapunov Exponent	δ_p^*	Power Ratio	Lyapunov Exponent
Number 1	0.0201	0.9585	1.4570	0.0181	0.9363	0.3018
Number 2	0.0099	0.9678	1.5811	0.0187	0.9013	2.5161
Number 3	0.0251	0.8689	0.7637	0.0390	0.8911	0.2785
Number 4	0.0082	0.9459	0.8771	0.0064	0.9789	0.8156
Number 5	0.0142	0.9646	0.9504	0.0126	0.9570	1.2138
Number 6	0.0030	0.9703	1.4919	0.0457	0.7424	0.4811
Number 7	0.0027	0.9837	0.9653	0.0659	0.8705	0.3417
Number 8	0.0108	0.9663	0.8391	0.0720	0.8492	0.7562
Number 9	0.0030	0.9839	1.4436	0.0098	0.9260	0.6700
Number 10	0.0031	0.9833	1.0239	0.2038	0.6795	0.3694
Number 11	0.0370	0.9413	0.6017	0.0186	0.9112	0.5267
Number 12	0.0278	0.9572	1.5629	0.0160	0.9364	1.3752
Number 13	0.0135	0.9292	1.1301			
Number 14	0.0143	0.9324	0.8867			
Number 15	0.0327	0.8597	0.7924			

*Standard Deviation (SD)

Table 2. Standard deviation of power spectrum, low frequency power ratio and Lyapunov exponents (mediolateral direction) for young and elder participants in the fifth 30-second test.

	Young Subjects			Elder Subjects		
	δ_p^*	Power Ratio	Lyapunov Exponent	δ_p^*	Power Ratio	Lyapunov Exponent
Number 1	0.0106	0.9625	1.5341	0.0151	0.9431	0.1617
Number 2	0.0042	0.9629	1.9008	0.0720	0.8313	0.1572
Number 3	0.0122	0.9508	1.6441	0.0332	0.9309	0.1334
Number 4	0.0061	0.9737	0.7405	0.0086	0.9483	0.4671
Number 5	0.0317	0.8752	0.8697	0.0019	0.9791	0.2721
Number 6	0.0048	0.9577	1.1362	0.1982	0.6686	0.4895
Number 7	0.0243	0.8823	0.9851	0.0184	0.9113	0.1631
Number 8	0.0019	0.9833	1.9531	0.0354	0.8681	0.2592
Number 9	0.0039	0.9816	1.7873	0.0058	0.9772	0.9332
Number 10	0.0140	0.9317	0.9527	0.0141	0.9318	0.2347
Number 11	0.0110	0.9558	1.8411	0.0489	0.8087	0.4496
Number 12	0.0065	0.9617	0.8431	0.0311	0.9124	0.6479
Number 13	0.0810	0.8370	1.1750			
Number 14	0.0099	0.9160	1.5307			
Number 15	0.0115	0.9411	1.2437			

*Standard Deviation (SD)

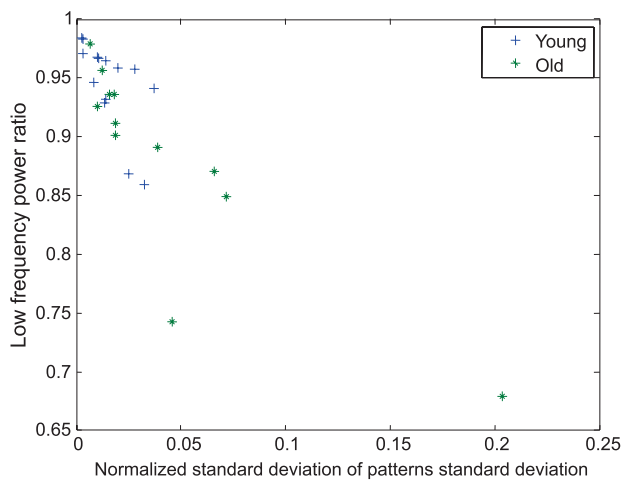


Figure 1. Comparison of standard deviation and low frequency power ratio in the fifth 30-second anteroposterior direction test.

This can be understood as the preference of the frequency features in posture signal discrimination. It seems that among the features used, low frequency power ratio is the most discriminating factor. So this feature is integrated to the largest Lyapunov exponent (Figure 3). Here the patterns are also somewhat overlapped but totally it is seen that for young subjects the largest Lyapunov exponent and low frequency power ratio values are larger than their corresponding values for the elders.

The same experiments were performed in mediolateral direction. Similar to the previous part of the experiment, Figure 4 demonstrates more discriminating features compared to Figure 5 for the both groups' posture signal classification. In Figure 4 the patterns are highly overlapped in feature space and they cannot be easily distinguished. This issue expresses the superiority of frequency-based methods in mediolateral direction.

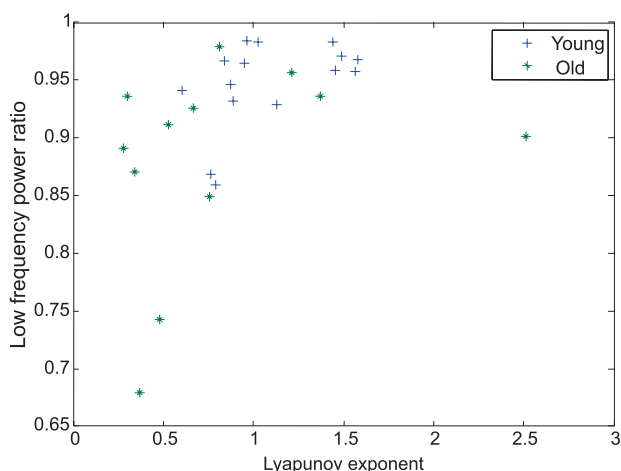


Figure 3. Largest Lyapunov exponents for subjects of both age groups (anteroposterior direction).

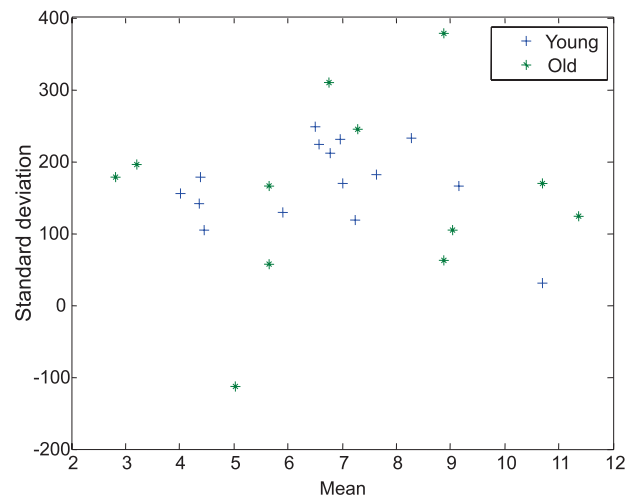


Figure 2. Comparison of mean and standard deviation in the fifth 30-second anteroposterior direction test.

It seems that among the defined features, the low frequency power ratio factor is preferred in posture signal discrimination. So it is integrated to the largest Lyapunov exponent of the signals to attain the feature space shown in Figure 6.

Similar to the anteroposterior direction, the young participants have larger Lyapunov exponents in mediolateral direction compared to the elder participants. Low frequency power ratio factors in the posture signals of young participants were also slightly larger than the elder participants.

DISCUSSION

Three factors of visual patterns and sensory receptors are among the main issues in static balance. The participants of this study had no difficulty and abnormality in these issues and their eyes were kept closed during the tests.

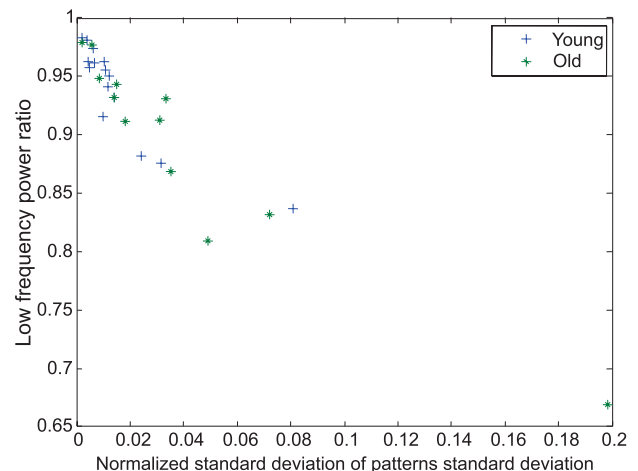


Figure 4. Comparison of standard deviation and low frequency power ratio in the fifth 30-second mediolateral direction test.

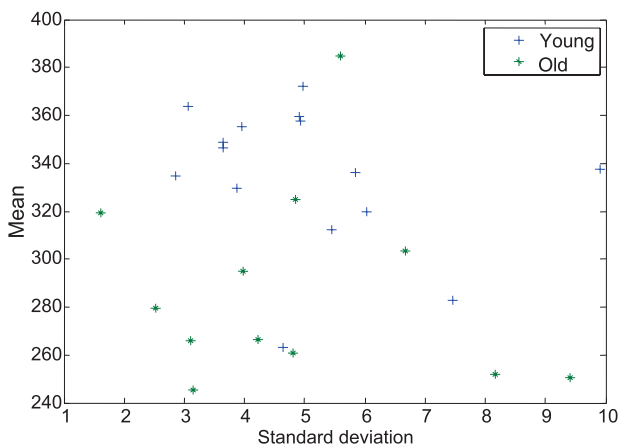


Figure 5. Comparison of mean and standard deviation in the fifth 30-second of mediolateral direction test.

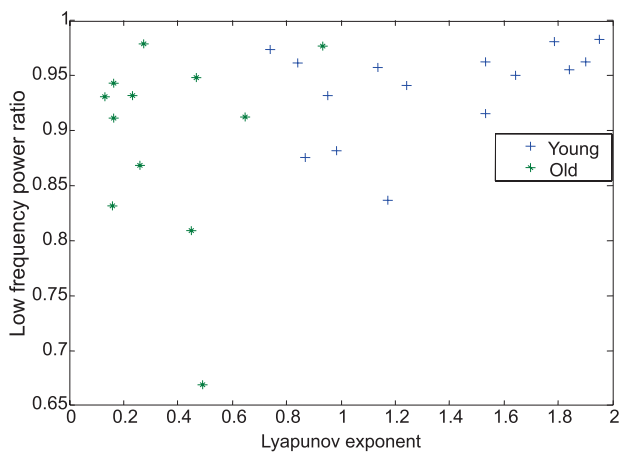


Figure 6. Largest Lyapunov exponents for subjects of both age groups (mediolateral direction).

Therefore the most likely important factor affecting the balance of the subjects was their body sensory receptors which were distributed in several parts of the body.

Among the four invested parameters for elder and young participants' posture signal discrimination, two parameters of mean value and standard deviation of the signal cannot distinguish the posture signals well. Instead, low frequency power ratio and standard deviation of the power spectrum were applied on the normalized signals and the signals were invested in frequency domain. These two features showed better performance in posture signals discrimination comparatively. Hence, working in frequency domain would be preferred compared to working in time domain for posture signals.

In addition, because of the higher difference in the low frequency power ratio of elder and young participants in anteroposterior direction, using this parameter in this direction is preferred. For justification, a physiologic observer can be used. Proprioceptive receptors located

at the bottom of the insoles in standing position yield us feedbacks on whether the majority of the body weight is stood on rear side area or front side area of the insole and this feedback is sent to the brain. So the state correction commands are returned from the brain to the skeletal muscles which are most likely affected in anteroposterior direction. Therefore as the age increases and the performance of the proprioceptive receptors are declined, static anteroposterior balance is affected more. Also, if an elder person loses his/her balance in walking, falling down is more probably from the front and it can be understood that with ageing, balance control declining is emerged more in anteroposterior direction.

Positive Lyapunov exponents in posture signals of elder and young participants indicated that the balance control system of the body is not a regular dynamic system. This means that there are no certain frequencies and regular predictable behaviors and it has a large number of dominant frequencies. Even in the case the person standing with no movement, a small change in the state of balance causes the control system to show a rapid response to keep the body in a balanced state as the control feedback. Higher Lyapunov exponents in the posture signals of the young subjects compared to elder ones demonstrate the robustness and responsibility of their control system as a nonlinear complex system. It shows the capability of a more rapid response for balance control.

CONCLUSION

Among the parameters used in this paper, two parameters of Lyapunov exponents and low frequency power ratio compared to other features demonstrate more discriminative and representative behavior for distinguishing elder and young participants' posture signals.

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CONFLICT OF INTEREST

None declared.

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