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Saccadic eye movements and their influence on kinematics of several body segments in the elderly while standing

LUCIA BIZOVSKA*, MILENA VAGAJA, DIANA MIHALOVA, MIROSLAV JANURA

Palacky University Olomouc, Faculty of Physical Culture, Olomouc, Czech Republic.

Purpose: It is well known that postural stability is influenced by visual stimuli. The influence of saccadic eye movement on postural control has been described, however, a specific response of different body segments has not been studied yet. Therefore, the aim of this study was to assess the effect of horizontal and vertical saccadic eye movements on postural stability with specific focus on upper trunk, lower trunk and lower limbs movement variability and complexity. *Methods:* Eighteen elderly participants (aged 70.3 ± 7.7 years) stood in bipedal stance in three visual conditions – horizontal saccades, vertical saccades and fixation. Accelerometers were attached to their lower back, sternum and shanks. Movement variability of each body segment was described by root-mean-square and sample entropy of acceleration. *Results:* The results of the present study revealed significant influence of saccadic eye movements on anterior-posterior and vertical shanks, and vertical lower trunk movement variability described by root-mean-square. *Conclusions:* The correlations between results of the observed segments showed segment-specific variability patterns but generalised complexity pattern.

Key words: *accelerometer, sample entropy, root-mean-square*

1. Introduction

Postural control depends on the integration of sensory information, including information from visual system. Importance of visual information in postural control has been studied and proven for all age-groups [8], moreover, it is well-known that the loss of visual information has negative impact on postural control [1], [14]. It has also been established that visual stimuli which cause eye movements can have positive or negative effect on postural stability (e.g., Aguiar et al. [2], Rodrigues et al. [17]).

With regards to eye movement, in addition to fixation, two basic eye movements have been defined – saccadic and smooth-pursuit eye movements [7]. The smooth-pursuit eye movements have mostly destabilising effect in static bipedal stance [9], [22] and dynamic situation when standing on the movable platform [18], however, studies have been found in which positive effect of smooth pursuit eye movements on postural control was shown [17]. On the other hand, saccadic eye movement have positive effect on postural stability [2], [16], [17] with the exception of difficult postural conditions – tandem stance – in which saccades had destabilising effect [12]. It has also been suggested that frequency of the saccades may influence the results because of the feedforward mechanism of postural control and the decreasing time for planning of the eye movement with increasing frequency of saccades [2], however, the conclusions were conflicting [2], [17], [20].

The above-mentioned studies rarely aimed at movement of different body segments. Head and trunk movement was similarly influenced by saccades and fixation in bipedal stance [2], [16], [21], however, no direct comparison between head and trunk kinematics was performed. It can be expected that, based on the strategy employed for postural stabilisation, influence of visual stimuli on various body segments, including

* Corresponding author: Palacky University Olomouc, Faculty of Physical Culture, Trida Miru 117, 771 11 Olomouc, Czech Republic. Phone: + 420 777 830 724, e-mail: lucia.bizovska@gmail.com

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lower limbs, would differ. Thus, the aim of this study was to assess the influence of saccadic eye movements on postural activity (body acceleration) with specific focus on several body segments.

2. Methods

Participants

Eighteen elderly subjects participated in this study (3 males, 15 females, age 70.3 ± 7.7 years, height 164.4 ± 6.0 cm, body mass 74.7 ± 9.5 kg). The subjects were free of any musculoskeletal or neurological disorders, were able to perform daily activities without support or help and did not undertake any surgeries nor suffer any injuries of the musculoskeletal system within the time interval of one year before testing. Before the testing, the participants signed written informed consent forms. The study was approved by the institutional ethics committee.

Procedure

Participants were standing barefoot on the foam pad (Airex Balance Pad, Airex AG, Sins, Switzerland). Four 3D accelerometers (Trigno wireless system, Delsys Inc., Natick, MA, USA, sampling rate 148 Hz) were securely attached to the participants' sternum, lower back at the level of the fifth lumbar vertebra and on both shanks approximately 10 cm above the lateral malleolus. The acceleration signal in medial-lateral (ML), anterior-posterior (AP) and vertical (V) direction was recorded in each trial. Each trial lasted 30 seconds with trial starting after 2–3 seconds after the participants were positioned into the final comfortable position. The participants were asked to stand with eyes open and arms alongside with the instructions to stand as still as possible and follow the prescribed visual pattern. No instruction on feet placing was provided. Three visual patterns were implemented in the study: stationary target – fixation (a dot in the middle of the visual field), horizontal saccades (dot changing position in a horizontal direction with the frequency of 1.1 Hz with the total distance between the right and left position comprising a visual angle of 11° [2]), vertical saccades (dot changing position in a vertical direction with the frequency of 1.1 Hz with the total distance between the lower and upper position comprising a visual angle of 11° [2]). The projection screen was placed two meters ahead of participants. Three repetitions of each visual pattern were performed in randomised order.

Data analysis

After mean subtraction [13], the acceleration signals were filtered using the 4th order low-pass bidirectional Butterworth filter with a cut-off frequency of 10 Hz. From acceleration signals, root-mean-square (RMS) as a characteristic of variability was computed in each direction. In addition, complexity expressed by sample entropy (SampEnt) was computed from each time series with the number of consecutive points m set to 2 and radius r set to 0.15 [4]–[6], [10]. The computed variables from acceleration signals from shanks were averaged for both lower limbs. The resulting variables for body sway description were as follows: shanks, lower back and sternum acceleration SampEnt in V, ML and AP directions; shanks, lower back and sternum acceleration RMS in V, ML and AP directions. Data analysis was performed in the software MatLab (R2017b, MathWorks, Inc., Natick, MA, USA).

Statistical analysis

The resulting variables were averaged among three repetitions. Shapiro–Wilk test did not confirm normal distribution of all variables. Therefore, Friedman Analysis of Variance was implemented for assessment of the effect of visual conditions, followed by post-hoc analysis by Wilcoxon test. The significance level was set to 0.05 with Bonferroni adjustment for multiple comparison resulting in the significance level of 0.05/3 = 0.017. Furthermore, correlation analysis by Spearman correlation coefficients was performed in each visual condition between acceleration characteristics of different segments. Each direction was considered separately. The statistical analysis was performed in software Statistica (v. 12, StatSoft, Inc., Tulsa, OK, USA).

3. Results

Statistically significant influence of visual conditions was found for shanks RMS of AP acceleration ($p = 0.029$) (Table 1) with the post-hoc results showing significantly higher value in condition with fixation, compared to horizontal saccades ($p = 0.011$). Statistically significant effect of visual conditions was also found for shanks RMS of V acceleration ($p = 0.002$) with significantly lower RMS value while performing horizontal saccades, compared to fixation ($p < 0.001$). Furthermore, lower back RMS of V acceleration ($p = 0.002$) was significantly lower while performing horizontal saccades, compared to fixation ($p = 0.001$) and significantly lower while performing horizontal saccades, compared to vertical saccades ($p = 0.006$). No statistical differences were found in sample entropy values (Table 2).

Spearman correlation coefficients (Table 3) showed statistically significant relationship between RMS of different body segments in AP and V direction for almost all combinations. In ML direction, only the relationship between lower back and sternum was statistically significant ($r = 0.69 – 0.80$). The significant correlations of SampEnt were found for all segments and conditions except for AP lower back and sternum relationship and shanks and lower back relationship in conditions with fixation and vertical saccades.

Table 1. RMS of segmental acceleration

		Fixation			Horizontal saccades			Vertical saccades		
		Median	LQ	UQ	Median	LQ	UQ	Median	LQ	UQ
V	Shanks	**0.0067**	**0.0059**	**0.0092**	**0.0057**	**0.0049**	**0.0076**	**0.0063**	**0.0057**	**0.0078**
	Lower back	**0.0084**	**0.0066**	**0.0101**	**0.0072**	**0.0061**	**0.0086**	**0.0075**	**0.0069**	**0.0099**
	Sternum	0.0091	0.0077	0.0112	0.0089	0.0074	0.0095	0.0090	0.0080	0.0107
AP	Shanks	**0.0103**	**0.0088**	**0.0127**	**0.0090**	**0.0079**	**0.0105**	**0.0095**	**0.0086**	**0.0106**
	Lower back	0.0104	0.0083	0.0126	0.0093	0.0082	0.0117	0.0100	0.0082	0.0126
	Sternum	0.0116	0.0109	0.0135	0.0114	0.0096	0.0140	0.0120	0.0102	0.0139
ML	Shanks	0.0093	0.0086	0.0103	0.0085	0.0070	0.0099	0.0088	0.0077	0.0101
	Lower back	0.0065	0.0051	0.0080	0.0066	0.0053	0.0075	0.0058	0.0050	0.0071
	Sternum	0.0070	0.0056	0.0082	0.0067	0.0057	0.0074	0.0065	0.0051	0.0075

AP – anterior-posterior, LQ – lower quartile, ML – medial-lateral, UQ – upper quartile, V – vertical; $p < 0.05$ for effect of conditions; bold values are significant.

Table 2. Sample entropy results for segmental acceleration

		Fixation			Horizontal saccades			Vertical saccades		
		Median	LQ	UQ	Median	LQ	UQ	Median	LQ	UQ
V	Shanks	0.57	0.56	0.58	0.57	0.56	0.58	0.57	0.56	0.58
	Lower back	0.55	0.53	0.58	0.56	0.54	0.58	0.55	0.52	0.57
	Sternum	0.53	0.48	0.55	0.50	0.45	0.56	0.50	0.46	0.56
AP	Shanks	0.48	0.39	0.54	0.48	0.44	0.55	0.49	0.43	0.53
	Lower back	0.27	0.23	0.37	0.31	0.24	0.34	0.28	0.26	0.36
	Sternum	0.39	0.30	0.44	0.35	0.29	0.41	0.32	0.30	0.42
ML	Shanks	0.43	0.38	0.52	0.45	0.39	0.50	0.43	0.41	0.52
	Lower back	0.50	0.37	0.54	0.48	0.38	0.51	0.49	0.42	0.53
	Sternum	0.42	0.36	0.47	0.41	0.34	0.50	0.43	0.37	0.47

AP – anterior-posterior, LQ – lower quartile, ML – medial-lateral, UQ – upper quartile, V – vertical.

Table 3. Spearman correlation coefficients between segmental body movement characteristics

		RMS			SampEnt		
		fixation	horizontal saccades	vertical saccades	fixation	horizontal saccades	vertical saccades
V	Shanks & lower back	**0.85**	**0.78**	**0.72**	**0.79**	**0.70**	**0.84**
	Shanks & sternum	**0.80**	0.42	**0.63**	**0.52**	**0.74**	**0.58**
	Lower back & sternum	**0.79**	**0.62**	**0.77**	**0.65**	**0.63**	**0.61**
AP	Shanks & lower back	0.44	**0.71**	**0.71**	0.43	**0.48**	0.34
	Shanks & sternum	0.27	0.39	**0.47**	**0.68**	**0.60**	**0.59**
	Lower back & sternum	**0.53**	0.30	**0.49**	0.42	0.43	0.33
ML	Shanks & lower back	0.15	0.22	0.30	**0.78**	**0.83**	**0.71**
	Shanks & sternum	0.39	0.47	0.41	**0.74**	**0.76**	**0.72**
	Lower back & sternum	**0.80**	**0.69**	**0.77**	**0.85**	**0.72**	**0.74**

AP – anterior-posterior, ML – medial-lateral, RMS – root mean square, SampEnt – sample entropy, V – vertical; $p < 0.05$; bold values are significant.

4. Discussion

As saccadic eye movements were proven to have the influence on postural stability, but it was unclear if the body movement was influenced in the same pattern on different segments, the aim of this study was to assess the influence of saccadic eye movement on the variability and complexity of the movement of upper trunk, lower trunk and lower limbs. We assumed that saccadic eye movements could have different effect on the movement of different body segments based on the strategy implemented for postural control.

Based on our results, positive effect of saccadic eye movement was shown for variability of the shanks movement in AP and V direction and for lower trunk variability in V direction. In all cases, variability was higher in the condition while fixating the target than in the condition with horizontal saccades. Similar results showing positive effect of saccadic eye movement on postural stability had been shown before with various wide of base of support in young and elderly subjects [2], [16], [17]. Even though the results of the present study are in line with the results of the above-mentioned studies, it is important to highlight the differences in postural task which was tested. While in the above-mentioned studies the postural stability was tested while standing on the hard surface, eyes open and no vestibular stimulation indicating full postural control, more challenging postural task was used in the present study. It was shown that elderly subjects rely mostly on somatosensory information when controlling body posture [8]. Therefore, the task during which somatosensory system was negatively influenced would imply difficult postural conditions for elderly during which mostly vestibular and visual system would be used for body posture adjustments. Although, to the best of our knowledge, the influence of the saccadic eye movements during standing on the foam surface have not been investigated yet, Hunter and Hoffman [12] chose to investigate postural stability during tandem standing with cognitive dual task and simultaneously visual stimuli in terms of fixation and saccades in various directions were performed. Such combination can be considered challenging for young adults. Based on their results, the effect of eye movement was apparent only for medial-lateral centre of pressure movement variability with increased variability while performing saccades compared to fixation. The results of their study in comparison with the other studies conducted with less difficult postural tasks [2], [16], [17] seem to indicate that with increasing difficulty of postural task, induced saccadic eye movements have rather negative effect on body movement variability. The reason might be that with increasing difficulty of the postural task, the tracking of visual stimuli diverses the attention of participants from postural task causing decline in their performance. It might be similar as when cognitive dual task is employed during performance of the task (see model of Yogev-Seligmann et al. [24]). However, even though challenging postural task was performed in our study, the results of [12] were not confirmed.

The direction of saccades also plays an important role in evaluation. In the study [15], no differences in postural sway while performing saccades of different directions were found. The results of our study showed similar conclusion with the exception of variability of the lower trunk movement in vertical direction. In that case, we found lower variability while performing horizontal saccades, compared to saccades in vertical direction. Overall, it can be seen that saccadic eye movement in horizontal direction influences the variability of body movement the most.

During the stance on the foam surface, hip strategy is usually used for body stabilisation [11], [23]. Based on our results, upper trunk movement was not influenced by visual stimuli, which is in line with the isolation of upper and lower body while using hip strategy for compensatory movements during postural stabilisation. Postural stabilisation in the AP direction is of higher difficulty, compared to ML direction, due to anatomical degree of freedom in sagittal plane, compared to frontal plane [3]. The result of our study showed the influence of visual stimuli precisely in the movement of less control – anterior-posterior direction. Due to the usage of foam pad, also variability in vertical movement could be observed in shanks and lower trunk. Absent differences in upper trunk movement in vertical direction are also in agreement with the adoption of hip strategy for postural stabilisation.

Furthermore, the results of the present study show no influence of visual stimuli on sample entropy. Since sample entropy is a measure of automaticity of the movement, it can be suggested that the degree of automaticity was the same for all of the performed task, even though differences in variability were observed. For complexity, the correlations between body segments results showed at least mild relationship between every body segment in all directions and for all visual stimuli. Based on these relationships, it can be assumed that complexity of the movement is a variable that describes body movement in general patterns. As already shown in the literature, the complexity of the movement shows different behavioural characteristics and concepts, compared to simple variability of the movement with the focus on the evolvement of motor behaviour in time [19]. On the other hand, when looking at the results of variability, poor to strong correlations could be found. These results suggest the need of position-specific evaluation when assessing variability of the movement, but, on the other hand, add more proving evidence of more specific approach which complexity of the movement provides.

5. Conclusions

In conclusions, the results of the present study revealed significant influence of saccadic eye movements on vertical lower trunk, and anterior-posterior and vertical shanks movement variability described by root-mean-square. Horizontal saccades seem to have positive effect on shanks and lower trunk movement variability while standing, compared to fixation. Upper trunk variability was not influenced by visual stimuli, nor was the complexity of the movement influenced. The correlations between results of different body segments showed significant relationship between every observed segment in terms of complexity. These results add another proof of motor behaviour control to the existing field of literature suggesting segment-specific variability of the movement during bipedal stance but general complexity pattern of behaviour.

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