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Influence of changing frequency and various sceneries on stabilometric parameters and on the effect of adaptation in an immersive 3D virtual environment

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Purpose: The aim of the study was to examine the influence of different types of virtual sceneries and frequencies of movement of visual disturbances on stabilometric values as well as whether individual sceneries and changing frequency can minimize effect of adaptation of tested person to applied disturbances. *Methods*: There were 23 healthy participants. A person has been standing on a Zebris stabilometric platform. Virtual 3D environment was displayed by means of HMD Oculus Rift system. An open (a meadow) and closed (a room) sceneries were used. The sceneries moved along the sagittal axis and rotated around horizontal axis. The measurement lasted 30 seconds and in the middle of it frequency of translational movement was changed from 0.7 Hz to 1.4 Hz or from 1.4 Hz to 0.7 Hz. *Results*: The data were reported as medians of COP velocity and ellipse area. Visual disturbances caused the increase of these values in comparison with the tests conducted with open eyes. Results divided into periods (the first and the second 15 seconds) showed that in the first half of the test values were higher compared to the second half. The comparison of values obtained for open and closed scenery showed that higher values were recorded for open scenery. *Conclusions*: The comparison of both types of sceneries on the basis of COP velocity and ellipse area showed that open scenery had a greater impact on the measured stabilometric values. It was found out as well that people got accustomed to the applied disturbances, but this effect was lower in the open scenery.

Key words: *virtual reality, balance control, center of pressure, posturography*

1. Introduction

Tests of balance control are one of basic methods enabling the assessment of the human motor system [3]. Such tests usually consist of immobile standing in an upright position [2]. The analysis of obtained results enables an objective evaluation of possible balance disorders [14]. However, such performance of stabilometric tests is not sufficient in the cases which demand a separate analysis of individual senses responsible for keeping balance [16]. In those cases implementation of so called conflicts between senses is necessary (realised by delivering information contrary to various senses). Such measurements can be carried out, for example, by means of the application of unstable or flexible ground, special booths with movable walls and ground, the use of virtual reality technology (VRT) or combination of these methods [5], [17], [18]. This enables, among other things, the evaluation of a possibility of compensation of one sense by others, a diagnosis of the sense responsible for balance disorders [8], [9], [23] or can contribute to more effective sport trainings [22], [25].

VRT is one of the most cutting edge methods in rehabilitation. There are many results confirming advantages of this approach in treatment [6], [11], [19], [21]. Also systematic has been done on the influence of different VRT visual disturbances on an examined person. Akiduki and Tossavainen [1], [24] examined how differences of very simple sceneries (tunnel, cylinder and dots or randomized texture) influenced stabilometric parameters, Dokka and Keshner [7], [15] used background scenes that linearly moved in various

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frequencies, whereas Horlings [12] conducted measurements during normal use of VRT without any disturbances. They all found some relationships between parameters of virtual environment and body balance. Interesting research was conducted by Robert et al. [20] who created the virtual environment as a reproduction of the gait laboratory and found differences in balance keeping in similar physical and virtual environment. Unfortunately most of this kind of tests were done by means of VRT devices without full immersive effect, what can be important considering the fact that the field of view can increase body sway [10].

All the afore-mentioned research gave an answer whether virtual environment has direct impact on balance, but they don't check the potential effect of adaptation to applied disturbances. Such effect was found in Michnik's research [18] which showed that during 30 seconds of test the value of amplitude in frequency analysis decreased and that the change of the disturbances frequency can eliminate this effect.

The goal of this study was to examine whether changing of disturbances frequency as well as a type of scenery have influence on values of typical stabilometric parameters of healthy people (COP velocity and area of 95% confidence ellipse) and whether the effect of minimization of adaptation can be seen in stabilometric values as well.

2. Methods

2.1. Subjects

23 volunteers – 11 females and 12 males – at the age of 20–24 participated in the research (average weight – 71 kg, average height – 1.79 m). Each person declared that is healthy and had no problems with their body balance. This study was previously approved by the Ethics in Research Committee of the Academy of Physical Education in Katowice (protocol number 11/2015).

2.2. Instrumentation

There were two 3D virtual scenes. The first one consisted of a 3 m wide by 3 m high by 3 m deep room (close scene). The second one consisted of a meadow with trees, sky and clouds, where horizon was in a distance of 100 m (open scenery). The 3D sceneries were developed with the use of the Quazar3D environment. Subjects viewed a virtual environment via an Oculus Rift System.

Oculus system is one of Head Mounted Displays (HMD) systems which consists of two screens in a housing mounted on a head. Images are displayed in resolution equal to 1920 × 1080 at 70 Hz and are presented in a way simulating 3D effect. An accelerometer mounted in the housing and a camera placed in front of the person enable tracking of a head position. Oculus system is an immersive system – that means that a subject feels like in a real 3D world.

To determine COP velocity and area of 95% confidence ellipse a Zebris FDM-S platform was used. Zebris FDM-S is a force-measuring platform with built-in capacitive force sensors enabling measuring and analysis of force distribution under feet (dimensions: 69 × 40 × 2.1 cm, Sensor surface: 54 × 33 cm, number of sensors: 2.560, sampling rate: 100 Hz).

2.3. Protocol of measurements

Subjects were asked to complete static balance tasks in two environments: a physical environment (with open eyes) and virtual environment. A 3 minutes break was between each measurement. Measurements were conducted in the following order:

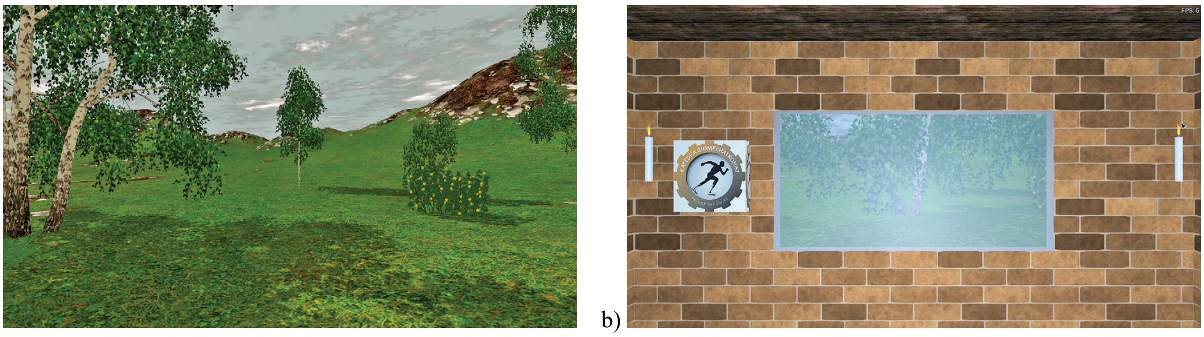
a) b)


Fig. 1. Sceneries used in measurements: a) the open scenery with items in the distance greater than 100 meters, b) the close scenery with items in the distance less than 3 meters

- eyes open,
- closed scenery,
- open scenery.

Measurements with open eyes were carried out without HMD because according to Robert et al. [20] and Morel et al. [19] wearing the HMD did not increase COP displacement. Each task lasted 30 seconds and subjects stood on a Zebris platform (Fig. 2).

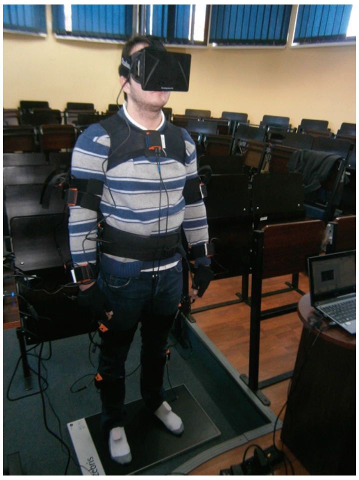


Fig. 2. Measurement position

In virtual environment subjects were exposed to harmonic movements of surroundings. There were two simultaneous movements (which simulated movement similar to an earthquake):

- translation along the sagittal axis (y) according to the equation:

$$y = 15\ [\mathrm{cm}] * \sin(2 * \pi * f_t * t)$$

where f_t is frequency of translational motion and t is time;

- rotation about the transverse (horizontal) axis according to the equation:

$$fi = 1\ [\mathrm{deg}] * \sin(2 * pi * f_r * t)$$

where f_r is frequency of rotational motion and t is time.

Frequency f_r of rotational motion was set to $0.5 * f_t$, and in the case of translational motion there were two frequencies f_t: 0.7 Hz and 1.4 Hz (that means that f_r was equal respectively to 0.35 Hz and 0.7 Hz). Frequencies were changed in the middle of each task. There were two schemes of frequency changing:

- initial frequency f_t equal to 0.7 Hz changed into 1.4 Hz;
- initial frequency f_t equal to 1.4 Hz changed into 0.7 Hz.

The selection of the plane of motion was done based on of previous research which proved that scenery disturbances on this plane have the greatest impact on human balance [7].

2.4. Data analysis

The data were reported as medians, 25–75% quartiles as well as minimum and maximum values (obtained data were not normally distributed). Median of COP velocity for all subjects was calculated from mean values of velocities obtained for individual subjects as a quotient of the COP path length and the duration [4]. Median of ellipse area was obtained from values measured for individual subjects. The median values were calculated for the following data selection:

- the whole 30 seconds measurements (results both from measurements with eyes open and in virtual environment);
- individually for the first and second 15 seconds of the measurement (results both from measurements with eyes open and in virtual environment);
- individually for the open and close scenery (in this case all results from the same scenery were taken into account from all measurements regardless of the frequency of disturbances);
- individually for frequencies 0.7 Hz and 1.4 Hz (in this case all results obtained for the same frequency were taken into account from all measurements regardless of the scenery).

The significance of differences was evaluated using the Wilcoxon's test for dependent samples (it was assumed that differences were statistically significant for $p < 0.05$).

3. Results

3.1. Comparison of physical environment and virtual environment

All participants completed all the tests. None of them had problems to keep the balance.

The analysis of medians calculated for the tests indicates that the introduction of visual disturbances caused the increase of these values in comparison with the tests conducted with open eyes (Fig. 3).

The median values of individual measurements and a percentage growth in relation to the test with open eyes are presented in Table 1. The ellipse surface

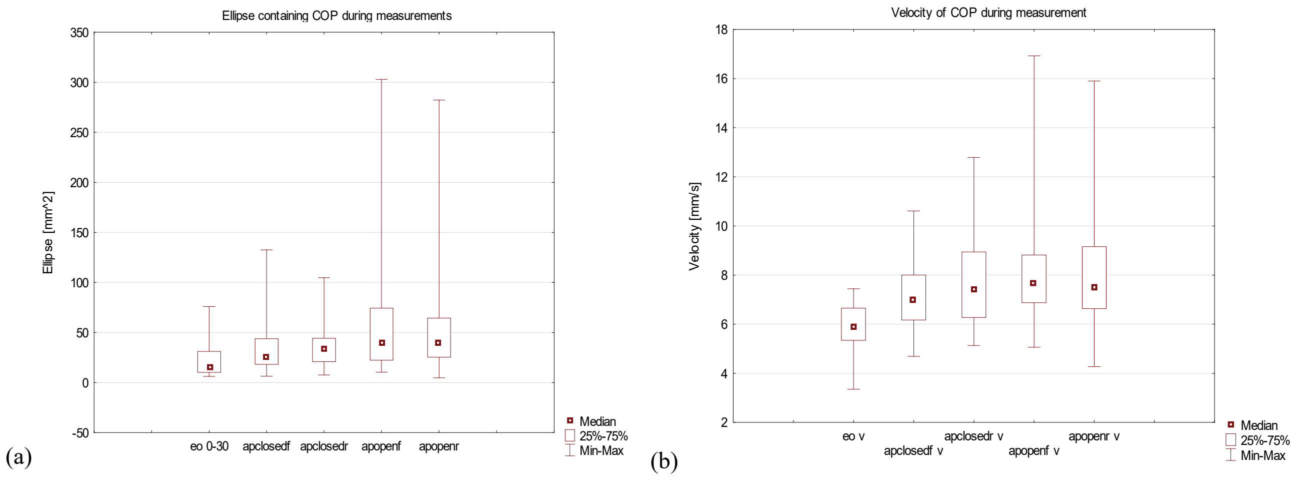


Fig. 3. Medians, 25–75% quartiles and minimum and maximum values of a) ellipse surface area [mm^2] and b) COP velocity [mm/s] obtained for 30 second measurements carried out with open eyes (eo), close scenery with decreasing frequency (apclosedf), close scenery with increasing frequency (apclosedr), far scenery with decreasing frequency (apopenf), far scenery with increasing frequency (apopenr)

Table 1. Median values of ellipse surface areas and COP velocities for individual measurements as well as a percentage growth in relation to the test with open eyes.
The following symbols means: open eyes (eo), close scenery with decreasing frequency (apclosedf), close scenery with increasing frequency (apclosedr), far scenery with decreasing frequency (apopenf), far scenery with increasing frequency (apopenr)

	Ellipse		Velocity	
	Area [mm^2]	Increase in relation to eyes open [%]	Velocity [mm/s]	Increase in relation to eyes open [%]
e.o.	14.9	0.0	5.9	0.00
apclosedf	26.0	74.5	7.0	18.6
apclosedr	34.2	129.5	7.4	25.4
apopenf	39.2	163.1	7.7	30.5
apopenr	40.4	171.1	7.5	27.1

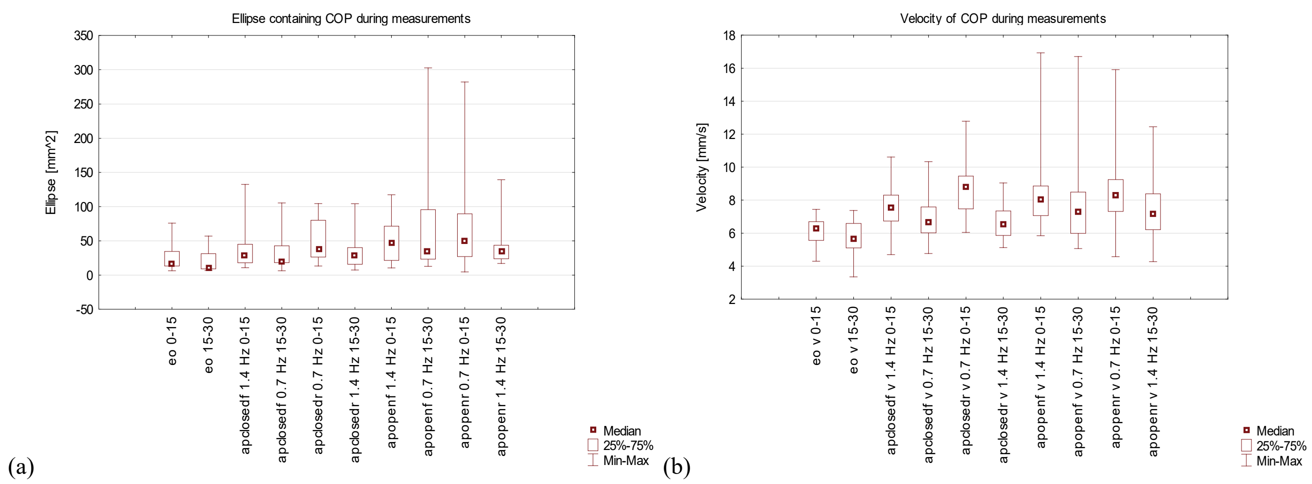


Fig. 4. Medians, 25–75% quartiles and minimum and maximum values of a) ellipse surface area [mm^2] and b) COP velocity [mm/s] obtained for initial and final 15 seconds of the test carried out with open eyes (eo), close scenery with decreasing frequency (apclosedf), close scenery with increasing frequency (apclosedr), far scenery with decreasing frequency (apopenf), far scenery with increasing frequency (apopenr). For each 15 seconds of the test value of used frequency of visual disturbances was showed

area compared to the tests conducted with open eyes increased by 74–171%, while the COP velocity by 18–30% (Table 1). All these differences between open eyes tests and 3D scenery tests were statistically significant ($p < 0.002$). However, it is noteworthy that both maximum values and 75% quartiles adopt values considerably greater than the determined medians.

3.2. Comparison of the first and second half of measurement

The analysis of the results of measurements divided into periods (the first and the second 15 seconds marked as 0–15 and 15–30) showed that the first half of the test recorded higher values, compared to the second half, of both analysed parameters (the COP velocity and ellipse surface – Fig. 4, Table 2).

The first 15 seconds showed higher values irrespective of the fact which frequency was first and which type of scenery was applied. However, statistically significant differences between the results obtained in the first and final 15 seconds occurred only in the closed scenery (both for COP velocity and ellipse area) and for tests with open eyes as well as for tests in open scenery with rising frequency in the case of COP velocity (Table 3).

3.3. Comparison of scenes and frequencies

Figures 5 and 6 present all measurement data collected with the division into scenery and frequency. It can be noticed again that the values of the analysed parameters in the case of introduced visual distur-

Table 2. Median values of ellipse surface areas and COP velocities for individual measurements with division into initial and final 15 seconds of test as well as a percentage growth in relation to the test with open eyes (respectively each scenery 0–15 in relation to eo 0–15 and scenery 15–30 in relation to eo 15–30). The following symbols means: open eyes (eo), close scenery with decreasing frequency (apclosedf), close scenery with increasing frequency (apclosedr), far scenery with decreasing frequency (apopenf), far scenery with increasing frequency (apopenr)

	Ellipse [mm^2]	Increase in relation to eyes open [%]	Velocity [mm/s]	Increase in relation to eyes open [%]
e.o. 0–15	17.2	0.0	6.3	0.0
e.o. 15–30	12.1	0.0	5.6	0.0
apclosedf 0–15	29.2	169.8	7.5	19.0
apclosedf 15–30	21.2	75.2	6.7	19.6
apclosedr 0–15	36.9	114.5	8.8	39.7
apclosedr 15–30	29.2	141.3	6.6	17.9
apopenf 0–15	46.3	169.2	8.0	27.0
apopenf 15–30	35.2	190.9	7.2	28.6
apopenr 0–15	50.1	191.3	8.3	31.7
apopenr 15–30	34.2	182.6	7.1	26.8

Table 3. Value of p coefficient in the Wilcoxon's test for dependent samples in comparison with results from the first and second period of measurement. Differences statistically significant ($p < 0.05$) are indicated by a star. The following symbols means: open eyes (eo), close scenery with decreasing frequency (apclosedf), close scenery with increasing frequency (apclosedr), far scenery with decreasing frequency (apopenf), far scenery with increasing frequency (apopenr)

	Value of *p* for COP velocity	Value of *p* for ellipse area
e.o. 0–15 → e.o. 15–30	0.020*	0.247
apclosedf 0–15 → apclosedf 15–30	0.014*	0.026*
apclosedr 0–15 → apclosedr 15–30	0.00005*	0.005*
apopenf 0–15 → apopenf 15–30	0.077	0.758
apopenr 0–15 → apopenr 15–30	0.046*	0.148

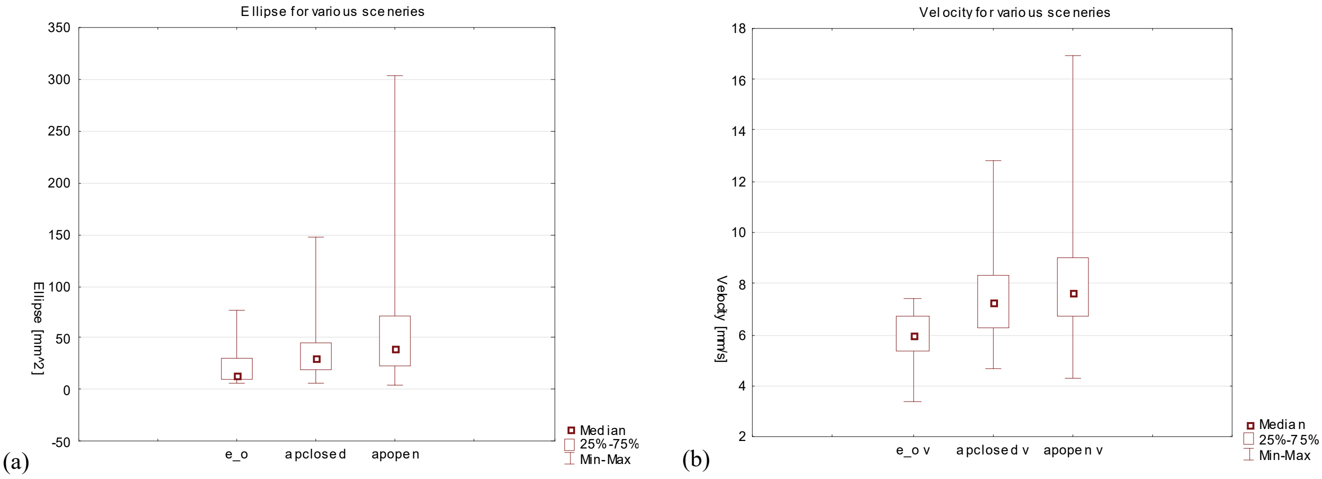


Fig. 5. Comparison of the influence of open and closed scenery on a) ellipse surface area and b) COP velocity. Medians, 25–75% quartiles and minimum and maximum values of 30 seconds measurements results are presented. eo – measurement with open eyes, apclosed – measurement in closed scenery, apopen – measurement in open scenery. Both differences between tests with open eyes and tests in sceneries as well as between tests in closed and open sceneries are statistically significant

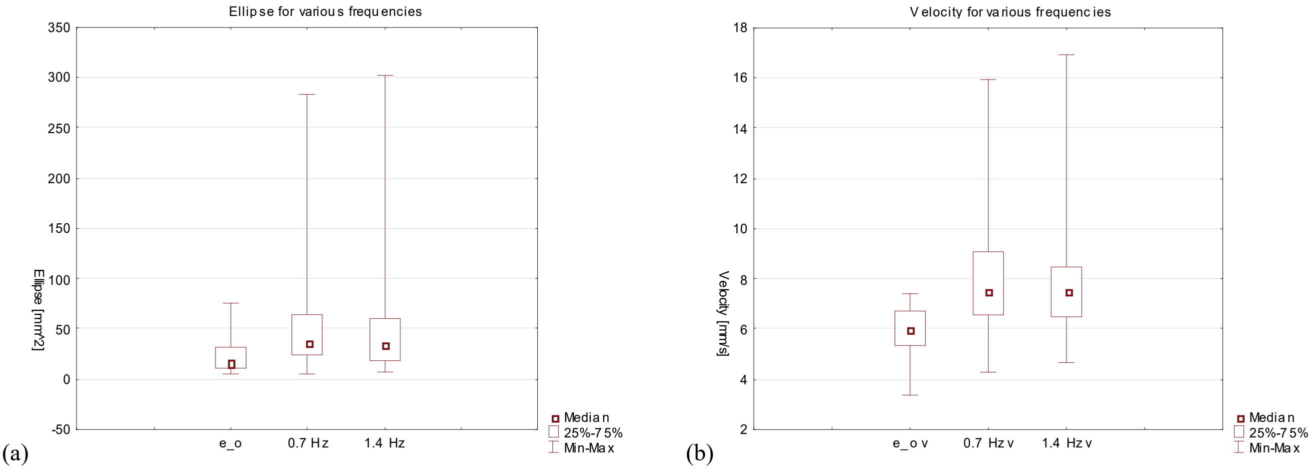


Fig. 6. Comparison of the influence of two various frequencies (0.7 Hz and 1.4 Hz) on a) ellipse surface area and b) COP velocity. Medians, 25–75% quartiles and minimum and maximum values of results grouped in terms of frequencies are presented. eo – measurement with open eyes, apclosed – measurement in closed scenery, apopen – measurement in open scenery. Only differences between tests with open eyes and tests in sceneries are statistically significant. No statistically significant differences were found for comparison between 0.7 Hz and 1.4 Hz frequencies

bances are much higher than the values obtained during the test with open eyes. This increase, in relation to results obtained for open eyes, reached 169.1% in the case of the ellipse surface area and 28.8% in the case of the COP velocity (Table 4).

The comparison of median values of the ellipse surface areas and COP velocities for open and closed scenery (Fig. 5, Table 4 apopen and apclosed) indicates that higher values of the measured parameters were recorded for open scenery (the increase of the ellipse median in relation to open eyes test by 100.7% in the case of closed scenery and by 169.1% in the case of open scenery and respectively in the case of the COP velocity by 23.7% for closed scenery and 28.8% for open scenery – results statistically significant, Table 5). The same analysis concerning two different frequencies (Fig. 6, Table 4, 0.7 Hz and 1.4 Hz) indicated that there are no similar statistically significant differences in the case of comparison of frequency 0.7 Hz with frequency 1.4 Hz (Table 5).

Table 4. Median values of ellipse surface and COP velocity for individual measurements with division into closed and open scenery and into frequencies 0.7 Hz and 1.4 Hz as well as increase of these values in relation to measurements with open eyes. Individual measurements as well as a percentage growth in relation to the test with open eyes. The following symbols means: open eyes (eo), close scenery with decreasing frequency (apclosedf), close scenery with increasing frequency (apclosedr), far scenery with decreasing frequency (apopenf), far scenery with increasing frequency (apopenr)

	Ellipse		Velocity	
	Area [mm^2]	Increase in relation to eyes open [%]	Velocity [mm/s]	Increase in relation to eyes open [%]
Eyes open				
	14.9	0.0	5.9	0.0
	Sceneries			
apclosed	29.9	100.7	7.3	23.7
apopen	40.1	169.1	7.6	28.8
Frequencies				
0.7 Hz	35.9	140.9	7.5	27.1
1.4 Hz	33.9	127.5	7.5	27.1

Table 5. Value of p coefficient in the Wilcoxon's test for dependent samples in comparison of results obtained for open eyes, open and closed scenery as well as for frequencies 0.7 Hz and 1.4 Hz. Differences statistically significant ($p < 0.05$) are indicated by a star

	Value of *p* for COP velocity	Value of *p* for ellipse area
Comparison of open scenery and eyes open	0.000*	0.000*
Comparison of closed scenery and eyes open	0.000*	0.000*
Comparison of frequency 0.7 Hz and eyes open	0.000*	0.000*
Comparison of frequency 1.4 Hz and eyes open	0.000*	0.002*
Comparison of open and closed scenery	0.0029*	0.0013*
Comparison of frequencies 0.7 Hz and 1.4 Hz	0.666	0.725

4. Discussion

4.1. Comparison of physical environment and virtual environment

Performed analyses concerned COP velocity and area of 95% confidence ellipse. It is assumed that the lower values of these parameters the more stabile posture of the tested person [13]. The increase of the analysed values in virtual environment in comparison with the tests conducted with open eyes (Fig. 3, Table 1) shows that the impact of VRT is significant and that means that the tested person's stability was unbalanced.

Additionally, great differences between median and maximal values point to the fact of existence of a great personal variability connected with the impact of virtual scenery on bodily posture stability. This fact is confirmed by research conducted by Akiduki et al. and Cousin et al. [1], [6]. In their research they determined mean values and standard deviations of the ellipse surface and the COP velocity while standing with open eyes and in the case of tests with the use of sceneries presented by means of virtual reality technology.

4.2. Comparison of the first and second half of measurement

In the Michnik's research it was found out that subjects can get accustomed to applied disturbances in virtual environment [18]. The aim of this work was to discover, among other things, if change of the frequency during measurement can eliminate the effect of adaptation. In the analysis of results divided into 15 seconds periods (Fig. 4) it was noticed that statistically significant differences (Table 3) between first and second period (first and second 15 seconds of measurement) were for the closed scenery in all cases and for the open scenery with rising frequency in the case of velocity (p was equal to 0.046 so the result was very close to $p = 0.05$ and to become statistically insignificant) as well as for the test with open eyes in the case of velocity. This can suggest, that the change of frequency in the open scenery was more effective in terms of elimination of the effect of adaptation than in the close scenery, but decrease of analysed values (therefore the possible effect of adaptation) was recorded in all cases, even for open eyes.

4.3. Comparison of scenes and frequencies

The differences in the effect of changing frequency in open and close scenery can point to the difference in the degree of influence of open and closed scenery on subjects. That is why all results were analysed in terms of type of scenery and applied frequency (Figs. 5 and 6). For both analysed values in comparison of sceneries (velocity of COP and ellipse area) the higher values were obtained for the open scenery and differences between open and closed scenery were statistically significant (Table 5). That may suggest, that open scenery has greater impact on subjects. Analysis of frequencies point to the lack of statistically significant differences between 0.7 Hz and 1.4 Hz. what suggests can suggest that both frequencies influence on subjects equally.

5. Conclusions

Obtained results proved that visual disturbances introduced during the tests have impact on the measured values describing balance of a standing person. The present study, based on analyses of COP velocity and area of 95% confidence ellipse, highlighted two features:

- the comparison of both types of scenery showed that open scenery had a greater impact on the measured stabilometric values,
- no similar statistically significant differences were found for the introduced frequencies (0.7 Hz and 1.4 Hz) of visual disturbances.

It was also noticed that during the test participants tended to get accustomed to the testing method (the values of the parameters measured were lower in the second half of the test) regardless of the scenery or frequency, however the effect of habit was lower in the open scenery.

It was also confirmed that the impact of disturbances introduced into virtual scenery affected participants in an individual way, i.e., showed individual variability. It suggests that exercises testing balance ability by means of VRT as well as diagnostic attempts with the use of such technology should take into consideration the above-mentioned individual variability by introducing, for instance, initial reference measurements.

Conflict of interest statement

Authors confirm that there nothing to disclose.

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