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The influence of frequency of visual disorders on stabilographic parameters

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Purpose: Defining the influence of parameters of visual disorders on ability of balancing turns out to be an important process in effective diagnostics. Current diagnostic methods relating mainly to determination of the coefficient of BRU™ (Balance Rehabilitation Unit Trade Mark) depend on lots of tests carried out in a disturbed environment created by Virtual Reality Technology. The aim of this study is to determine the effect of the frequency of visual disturbances on stabilographic values in the virtual reality environment. *Methods*: The study was carried out involving one research group in Virtual Cave. There were induced visual disturbances with different frequencies and with the change of frequency during measuring the position of the center of pressure (COP) in the test. Before each test the reference test was performed. All tests were performed with disorders in two different sceneries: closed and open scenery. All measurements were carried out on an immobile Zebris platform which enables determination of feet pressure distribution. From the measured values of the position of the COP Short Time Fourier Transform (STFT) was calculated. *Results*: The results of calculation are shown in graphs. Their analysis showed that changing the parameters of disorder frequency in world created using Virtual Reality Technology affects stabilographic parameters. The intensity of these changes is also affected by applied research scenery. *Conclusions*: Conditions have been set out to carry out similar studies in order to obtain reliable results. The study is the first step in a project to develop a system for diagnosis and rehabilitation of human movement using Virtual Reality Technology.

Key words: *balance, virtual reality, stabilography, 3D systems*

1. Introduction

Stabilography is one of the most common methods of evaluating the stability of posture, defined as the ability to keep balance – previously assumed body posture [16]–[18], [21]. It consists in analysing the resultant ground reaction forces evoked by the pressure of the feet on the ground while standing. The way of keeping balance proves the abilities of motor coordination. All incorrectness caused by the pathological changes in the nervous and motion systems, such as spine abnormalities or complications after stroke are reflected in the evaluation of stability [6], [8]. Obtained results can also help to assess the influence of treatment or rehabilitation exercises on recovery progress [2], [5], [9], [14]. Up till recently the stabilographic research was based on Romberg's test, the test performed while calm standing on both feet with open and then closed eyes. Nowadays, more and more often ten tests proposed by Medicaa® are carried out [3], based on which the unit BRUTM (The Balance Rehabilitation Unit) is established. In the course of examination the visual stimuli, in the form of 2D or 3D graphics, generated by means of Virtual Reality Technology is impacted by the patient's sense of sight. With the simultaneous measurement of the quantitative rates such as: the border of stability, the COP excursion and the area of ellipse, the following tests are performed in a standing position: with opened eyes, with closed eyes, on the soft ground, while evoking saccadic eye movements, with optokinetic stimulation of the eyes with an object

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moving from right to left and up and down, and visual disturbances in the saggital and coronal planes [1], [10], [11]. The use of the modern systems of Virtual Reality projection such as 3D helmets, used in similar research, or systems of Cave type [11], [13], allows the reality to be imitated in a very good way [12]. The spatial feeling is so real that it is difficult to distinguish the reality from the graphic created by the computer [19]. The use of such systems makes it possible to make the diagnostic and therapeutic processes [4] more individual and creates a very universal system [7], [15], while changes in the tests conducted and the scenery in which they are done are solely restricted to computer programming [7].

The aim of the research was to determine the influence of seperated visual disturbances on the balance maintaining with simultaneous lack of vestibular and proprioceptive stimuli. It was also determined how frequency of disturbances as well as the type of virtual scenery (closed or open) influence the ability to keep balance. All measurements were carried out in a Virtual Reality Laboratory by means of a system for the multiwall projection of 3D images (CAVE system). The results were interpretated taking into consideration the COP (Center of Pressure of foot on the measuring platform) position with the use of the Short Term Fourier Transform.

2. Material and methods

Subjects

24 volunteers – 15 females and 9 males (age: 20–28) – students of Biomedical Engineering Faculty at Silesian University of Technology participated in the research. Each person declared to be healthy and had no problems with balance. Participants gave a written informed consent to participate in research and publish the results.

Protocol

Two different 3D sceneries were developed for the needs of the research. The first one was a closed small room with 5 m long walls (Fig. 1a), where as the second one was an open space – a meadow with some trees in the distance and a horizon which seemed to be 100 m away (Fig. 1b). The sceneries were developed with the use of a Quazar3D environment and were displayed by means of a CAVE System enabling multiwall projection of three dimensional images.

The sceneries were used in the research to simulate motion of surrounding space (similar to an earthquake). The motion was a translational movement of a scenery realized in a sagittal plane combined with a rotational motion (which made the motion more realistic). The selection of the plane of motion was done on the basis of previous research, where it was determined that scenery disturbances in this plane affect human balance the most [9]. The translation amplitude was set at 30 cm and rotation amplitude was set at 5 cm.

A person being tested stood in the centre of the CAVE System, wearing special glasses which enabled the projected images to be seen as three dimensional world (so called immersive effect). Each test lasted 30 seconds and consisted in simulation of movement of surrounding space with a chosen frequency. In the

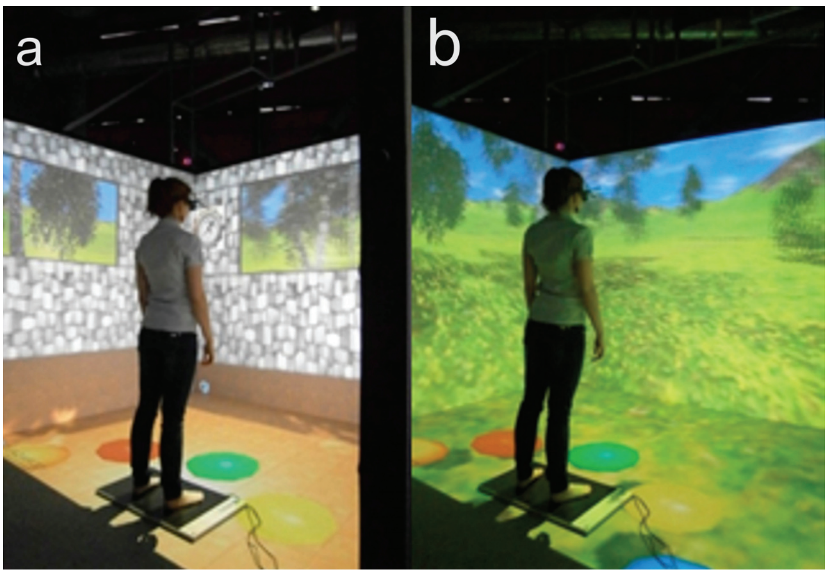

Fig. 1. Study view – closed and open scenery

middle of each test there was a change of frequency realized according to the following scheme:

- initial frequency 0.7 Hz changed into 1.4 Hz,
- initial frequency 1.4 Hz changed into 0.7 Hz.

Table 1. The study carried out

Research group	Frequency of study	Scenery
24 persons	Increase of the frequency from 0.7 Hz to 1.4 Hz	Closed
		Opened
	Decrease of frequency from 1.4 Hz to 0.7Hz	Closed
		Opened

Data collection and processing

Data collection was realized by means of the Zebris FDM-S Platform which enabled stabilographic measurements. For each test changes of position of the Center of Pressure (COP) were determined, which described oscillatory movement of the whole body. The platform was an immobile element placed on an immobile floor. All scenery movements were only unrealistic visual disturbances (realized using the CAVE System) without real movement of walls or basis.

In the next step, obtained results were processed with the use of Short Time Fourier Transform (STFT) and then frequency analyses were done similarly to McAndrew's research [12].

A 4-second span of the window for the Hamming window was taken into consideration and a 0.1 second window shift. A four second width of the window results in the fact that the first possibility to calculate a value for the amplitude of the shift by the means of the STFT algorithm is the value in the 2nd second (time window begins then at zero and ends at the 4th second), and the last value is calculated for the twenty-eighth second (time window begins at 26th second and ends in 30th). This leads to the lack of amplitudes in the time-frequency charts for time values less than 2 seconds and larger than 28 seconds. The calculated results were averaged for the hole group and then presented on logarithmic graphs. The mean value was calculated in the linear scale and then the upper and lower range was calculated as a mean value plus/minus standard deviation. Next, 10 log were calculated from the three courses and sketched on logarithmic graphs.

Next, the results obtained in this way, for each group of students, made it possible to prepare charts of time-frequency of STFT as well as profiles of amplitude cross-sections for disturbance frequency. These profiles present courses of changes with time of amplitude which correspond to selected frequency of distortion. The methodology of amplitude profile generation is shown in Fig. 2, where the following steps indicate:

- measurement of COP displacements in saggital plane for all subjects (Fig. 2a),
- calculation of Short Term Fourier Transform for obtained COP displacements (Fig. 2b),
- averaging spatial charts of Short Term Fourier Transform for the whole group tested (Fig. 2c),
- calculation of amplitude profiles from averaged charts carried out for disturbance frequencies 0.7 Hz and 1.4 Hz (Fig. 2d),

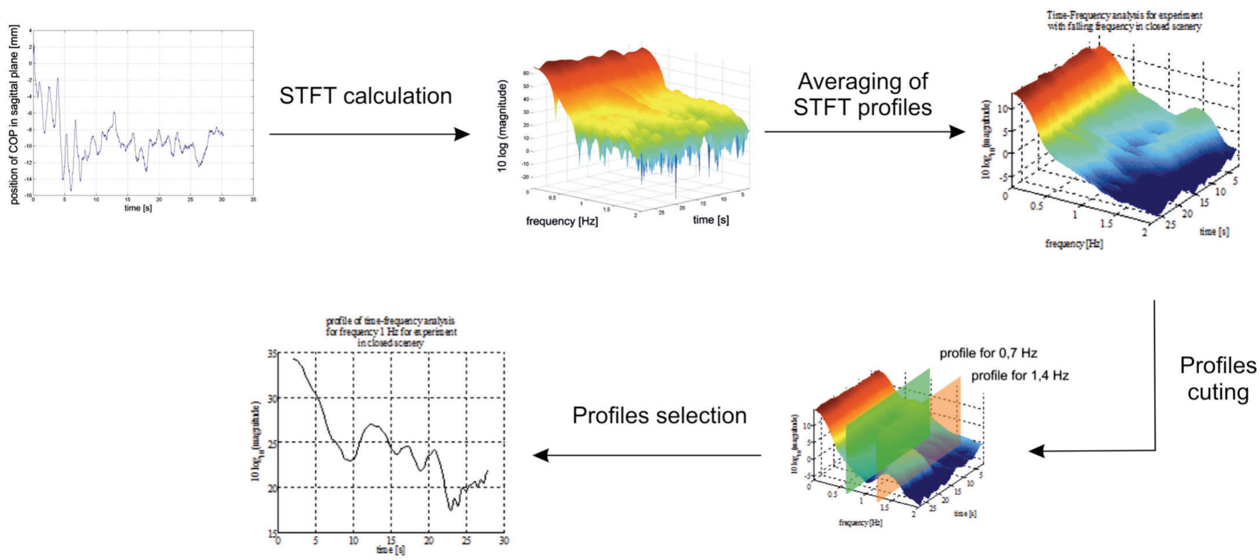

Fig. 2. Method of amplitude profile generation for individual frequencies. (a) displacement of COP in sagittal plane; (b) STFT obtained from COP displacement in sagittal plane; (c) averaged chart of STFT, (d) generation of amplitude profiles from averaged chart of STFT; (e) time function of amplitude profiles for both sceneries and tests carried out with increase and decrease of frequency

- analysis of amplitude profiles obtained for each scenery and for measurements carried out for a decrease and increase of frequency (Fig. 2e).

In order to analyze the influence of a change of frequency on COP motion amplitude profiles were divided into two periods of time:

- 0–15 corresponding to the first frequency,
- 15–30 corresponding to the second frequency.

For each period two characteristic values were found:

- the maximal value amplitude (max_0–15 and max_15–30) – this value shows when the disturbance has the greatest effect on tested person,
- the minimal value of amplitude which was reached between the maximal value of amplitude and the end of the analyzed period of time (min_0–15 and min_15–30).

These values were used to calculate two indexes (respectively for two periods of time) describing how a tested person gets used to scenery disturbances.

W15 = max_0–15 s – min_0–15 s,

W30 = max_15–30 s – min_15–30 s.

Estimation of the influence of scenery and frequency parameters on the examined person's balance required referential measurements based on a Romberg test (a person had to stand still with open eyes for 30 seconds on an immobile measuring platform without any visual disturbances). For the obtained results similar calculations were carried out as for tests with visual disturbances (Fig. 4).

3. Results

Time-frequency analysis of the results transformed by means of Short Term Fourier Transform

Measurements and calculations carried out during research enabled determination of frequency

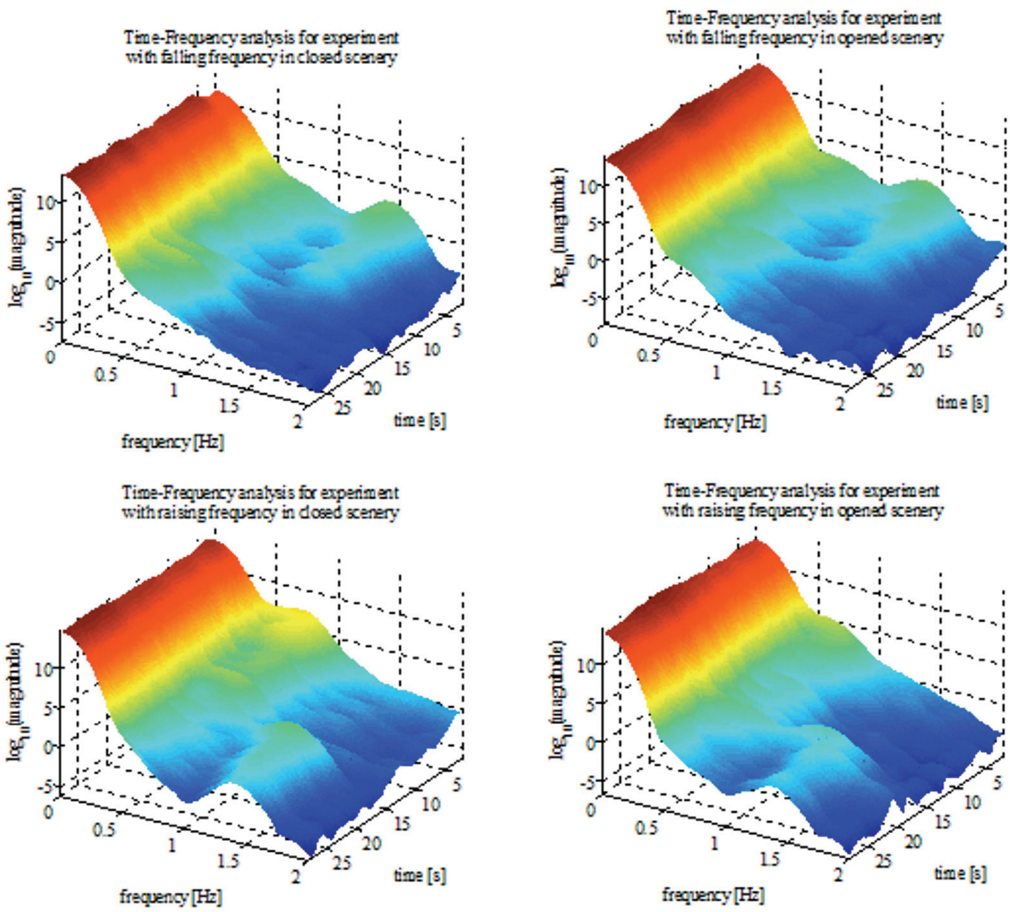

Fig. 3. Average time-frequency charts depicting the Short Term Fourier Transform (STFT using a Hamming window) from the value of the deviation of position of COP for sagittal axis in the closed and open scenery for the test group, with a change in frequency during the test. (a) Time-frequency analysis for experiment with falling frequency in closed scenery; (b) Time-frequency analysis for experiment with falling frequency in open scenery; (c) Time-frequency analysis for experiment with rising frequency in closed scenery; (d) Time-frequency analysis for experiment with rising frequency in open scenery

of oscillation of COP. These results are presented in the form of time-frequency courses of STFT (Fig. 3 – results obtained for both sceneries and for each series of tests with visual disturbances). Figure 4 presents results of referential measurement.

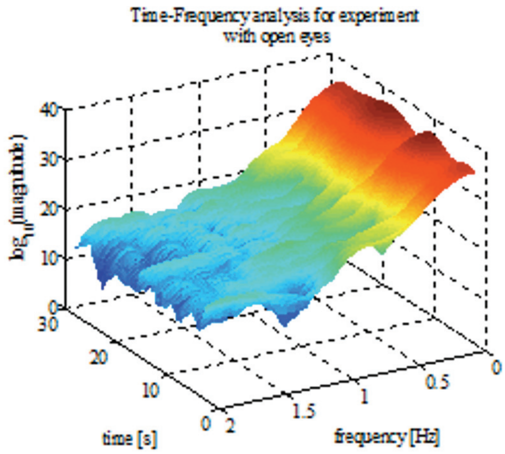

Fig. 4. Chart showing the result of Short Term Fourier Transform STFT for the signal of COP deviation calculated from the full form of the signal using a Hamming window obtained for the stabilometry measurements in standing position with open eyes without any disturbances (referential measurement)

Averaged cross-cutting charts of the values of Short Term Fourier Transform

According to the assumed methodology (Fig. 2) from the spectrograms obtained the time sections

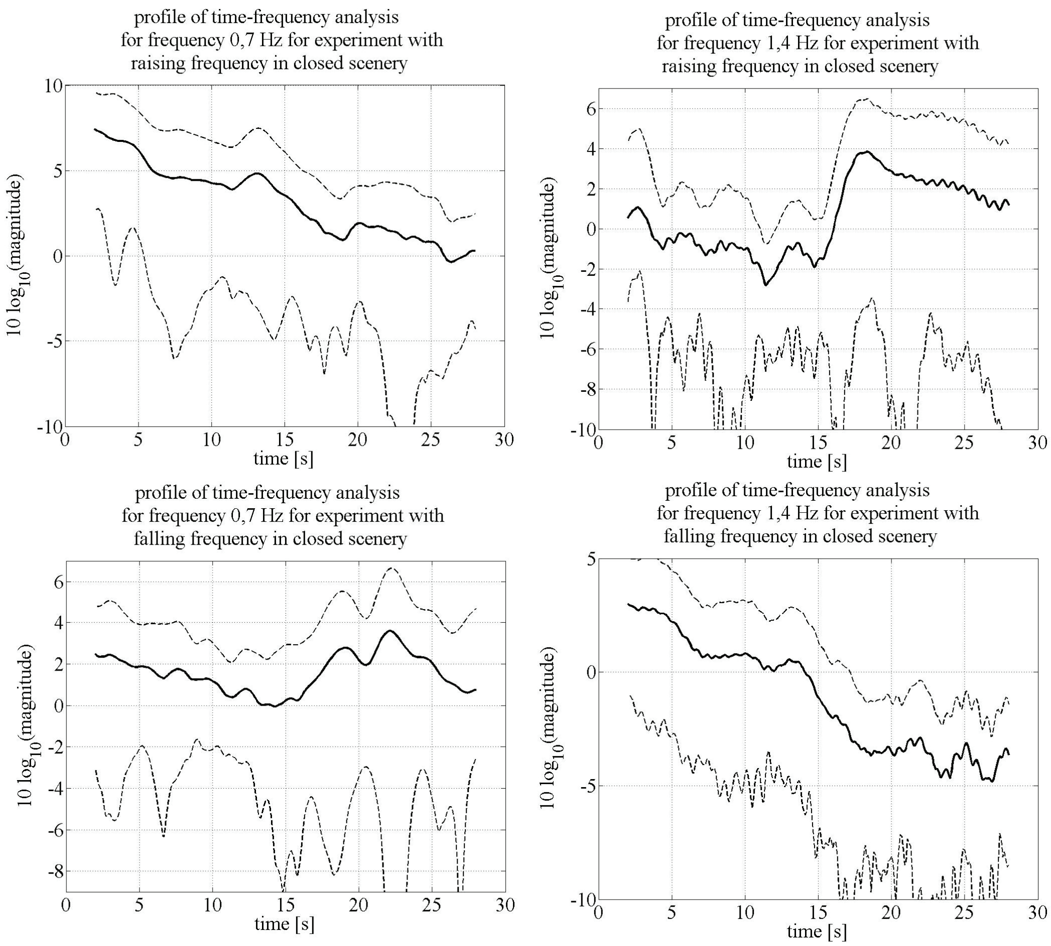

Fig. 5. Averaged cross-cutting charts of the values of Short Term Fourier Transform STFT (windowing with a Hamming window) from the value of deviation of the position of COP for saggital line in the closed sceneries for the frequency of disturbances of 0.7 and 1.4 Hz: (a) profile of time-frequency analysis for frequency 0.7 Hz for experiment with rising frequency in closed scenery; (b) profile of time-frequency analysis for frequency 1.4 Hz for experiment with rising frequency in closed scenery, (c) profile of time-frequency analysis for frequency 0.7 Hz for experiment with falling frequency in closed scenery; (d) profile of time-frequency analysis for frequency 1.4 Hz for experiment with falling frequency in closed scenery

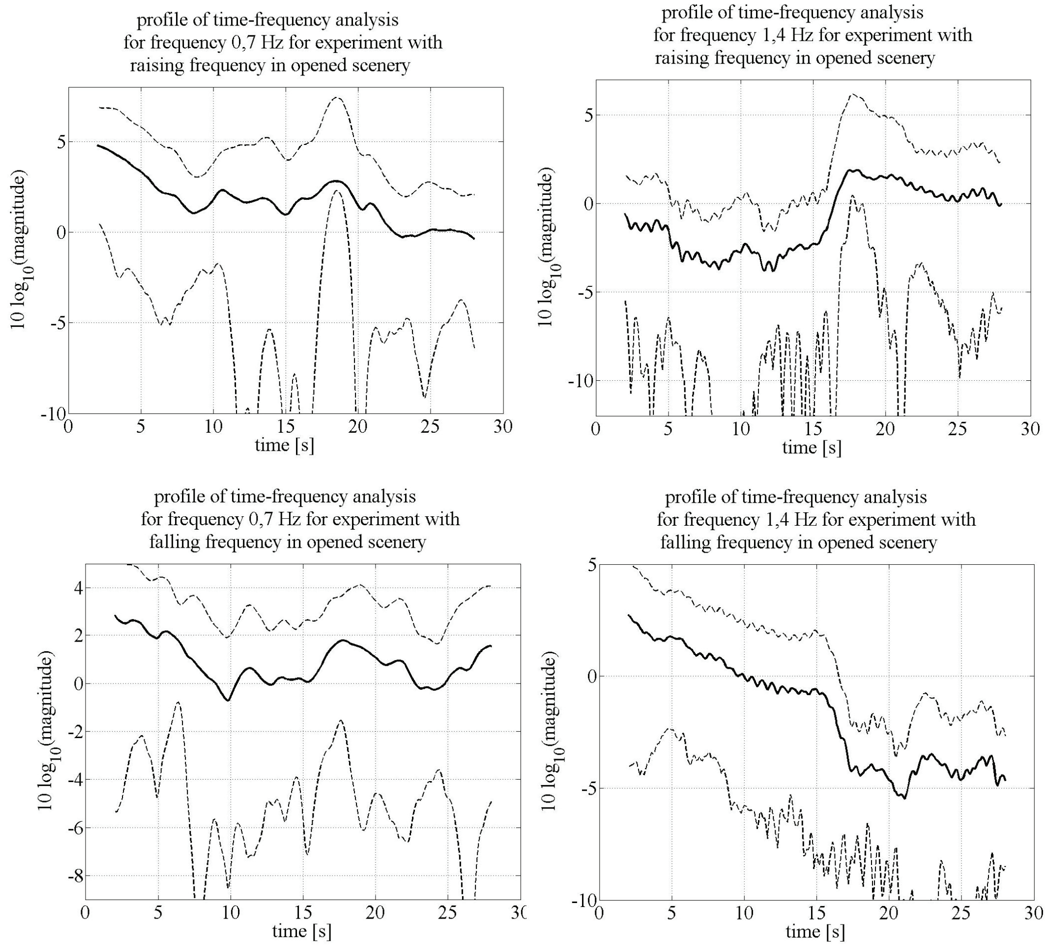

Fig. 6. Averaged cross-cutting charts of the values of Short Term Fourier Transform STFT (windowing with a Hamming window) from the value of deviation of the position of the COP for saggital line in the open sceneries, for the frequency of disturbances of 0.7 and 1.4 Hz: (a) profile of time-frequency analysis for frequency 0.7 Hz for experiment with rising frequency in open scenery; (b) profile of time-frequency analysis for frequency 1.4 Hz for experiment with rising frequency in open scenery; (c) profile of time-frequency analysis for frequency 0.7 Hz for experiment with falling frequency in open scenery; (d) profile of time-frequency analysis for frequency 1.4 Hz for experiment with falling frequency in open scenery

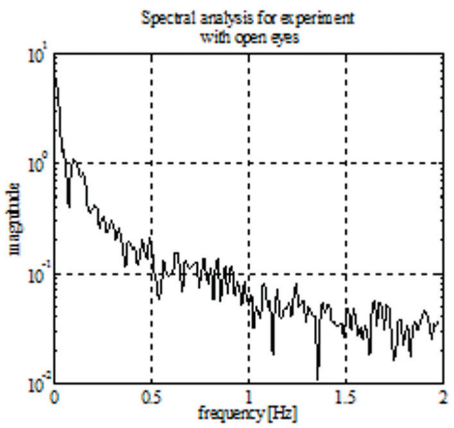

Fig. 7. Averaged cross-cutting charts of the values of Short Term Fourier Transform STFT (windowing with a Hamming window) from the value of the deviation of the position of the COP for saggital line obtained for the stabilometry measurements in standing position with open eyes without any disturbances

for the frequency of the disturbances were cut out (0.7 Hz and 1.4 Hz for the test group). The cross-sections are shown in Fig. 5 and Fig. 6. Results for referential test are presented in Fig. 7.

Indexes describing intensity of the influence of disturbances and a custom effect

Table 2 presents maximal and minimal values of amplitude of body oscillation (logarithmic units) taken from charts of frequency profiles. On the basis of these data one can define a level of the influence of visual disturbance changes on the balance of examined person. Values which correspond to frequency of disturbances are bolded. For example, the first column corresponds to COP amplitude for frequency 0.7 Hz (here, it is a frequency of COP oscillation – not frequency of scenery disturbances). For the frequency of scenery disturbances of 0.7, the value is bolded (0–15 s); for the frequency of scenery disturbances of 1.4 Hz the value

Table 2. Values of log (magnitude) for signal amplitude of COP position in sagittal plane (because the values in the table are in logarithmic units, negative values correspond to the amplitude of the value between 0 and 1

	Closed scenery			
	Study with rising frequency		Study with falling frequency	
	0.7 Hz profile	1.4 Hz profile	0.7 Hz profile	1.4 Hz profile
max 0–15 s	**7.5**	1.0	2.4	**3.0**
max 15–30 s	3.5	**3.7**	**3.5**	–1.0
min 0–15 s	**3.5**	–2.8	0	**–1.0**
min 15–30 s	–0.3	**1.0**	**0.8**	–5.0
W15	**4.0**	3.8	2.4	**4.0**
W30	3.8	**2.7**	**2.7**	4.0
	Opened scenery			
	Study with rising frequency		Study with falling frequency	
	0.7 Hz profile	1.4 Hz profile	0.7 Hz profile	1.4 Hz profile
max 0–15 s	**4.7**	–0.5	2.8	**2.7**
max 15–30 s	2.7	**1.9**	**1.7**	–0.8
min 0–15 s	**0.9**	–3.8	–0.7	**–0.8**
min 15–30 s	–0.3	**0**	**–0.2**	–5.2
W15	**3.8**	3.3	3.5	**3.5**
W30	3.0	**1.9**	**1.9**	4.4

is not bolded (15–30 s). In the same way indexes W15 and W30 are presented.

4. Discussion

Charts analysis

Within the frame of the research the influence of disturbances, realized in the 3D Virtual Reality scenery, on persons' ability to keep the balance was examined. To this end, measurements of COP oscillations were carried out. Next, in order to analyze the results obtained, like in McAndrew's research [12], profiles of frequencies of set transformations were determined, which can be seen on the frequency charts depicting the Short Term Fourier Transform (STFT using windowing with Hamming window), Fig. 3 and Fig. 4. These profiles were calculated from the value of COP oscillation amplitude in sagittal plane. The conclusion that external, visual disturbances really influence the examined persons' ability to keep the balance can be drawn from the existence of peaks on the charts. These charts present values of amplitude for various frequencies of COP oscillation. Peaks in these courses indicate that there is a frequency for which a value of amplitude is much bigger than for other frequencies. The value of this dominant frequency is equal to frequency of external disturbances. The remaining components of the deviation of the COP in the sagittal plane are much smaller and their amplitude decreases with frequency, which was also observed by McAndrew [12] and Mary Young [22] in terms of the gait.

One can also notice that a change of disturbance frequency is followed by a change of dominant frequency of COP motion. This shows that there is an influence of external, visual disturbances on ability to keep balance by examined subjects. In order to eliminate the possibility that examined persons oscillate in the same way without any external disturbances the referential measurement was carried out. Obtained results showed that there are no maxes of this kind on STFT courses, Figs. 3–6. High amplitude value for a very low frequency results from one's own fluctuation around the balance location and this phenomenon is the expected effect (the same was observed by Syczewska et al. [18]).

On the cross-cutting charts of the value of Short Term Fourier Transform STFT (Figs. 5 and 6) there is a clearly visible decrease of the amplitude of the dominant component with time. This is the result of getting used to the disturbances evoked. The stabilizing system learns to ignore the occurring disturbance. The change of the frequency of disturbance during the test resulted in the second rise of the amplitude for values of evoked disturbances at the same time cancelling out the effect of habit.

Index analysis

Maximal and minimal values of amplitude as well as W15 and W30 indexes (Table 2) enabled quantitative description of the effect of habit to disturbances as well as the influence of various sceneries on ability to keep balance.

One can notice that greater values of COP amplitude were measured for the closed scenery. This indicates that disturbances realized in such scenery have greater impact on the balance destabilization than those realized in the open scenery. The greatest difference between results obtained for two sceneries took place in the case of the test with increasing frequency for maximal amplitudes, at the beginning of the test, for 0.7 Hz (that was 7.5–4.7 = 2.8). The minimal difference was noticed for 1.4 Hz in the test with decreasing frequency (3.0–2.7 = 0.3 at the begining of disturbances and –1 – (–0.8) = –0.2 at the end, after 15 seconds).

When analysing the influence of various frequencies of disturbances one can notice that the frequency of 0.7 Hz had greater impact on the examined peoples' balance. There were greater oscillations of COP for this frequency. This conclusion is true for both sceneries and sorts of tests with one exception – a test in the open scenery with decreasing frequency when the maximal amplitude value (1.7) in the second part of the test (0.7 Hz) was smaller than the maximal amplitude value (2.7) in the first part of the test (1.4 Hz).

The effect of getting used to disturbances is slightly bigger for the closed scenery (the conclusion drawn from indexes W15 and W30 – greater value of indexes means greater effect of getting used). However, what is more important, one can notice that the final value of the amplitude of COP oscillation (after 15 seconds of disturbances with given frequency) in the closed scenery is greater at the end of the test (for example, 3.5 for the closed scenery and 0.9 for the open one – test with decreasing frequency, values obtained for the frequency of disturbances equal to 0.7 Hz). This means that after 15 seconds of the measurement in the closed scenery a person examined was still under the influence of visual disturbances whereas in the open scenery this influence was much smaller.

A comparison of two types of tests (increasing and decreasing of the disturbance frequency) shows that there are no significant differences in terms of the effect of getting used to visual disturbances.

5. Conclusions

The change of the frequency parameters of disturbances evoked by means of Virtual Reality Technology results in a change of stabilographic parameters. An impact of the frequency values on the intensity of these changes and an impact of the scenery used have been observed.

In the closed scenery, where the person examined is located in the virtually designed room, higher amplitudes of COP oscillations have been observed than in an open scenery, where the distance of the person examined from simulated objects is large. In the closed scenery the magnitude of COP oscillation was also greater after 15 seconds than in the open one.

It was also noticed that smaller frequency of external disturbances had a greater impact on tested persons than those of the greater frequency.

The present results show a link between selected parameters of external disturbances and persons' ability to keep balance. The tests indicated which of them had greater impact and how people get used to such visual simulations.

Additionally, the research provides a basic framework of a method for performing stabilographic diagnostic and treatment with the use of Virtual Reality Technologies.

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