The influence of the scenery and the amplitude of visual disturbances in the virtual reality on the maintaining the balance

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Abstract

Background & Study Aim: The process of the maintaining the balance is a very important human skill. All the changes, which impair the steering system or executive system are reflected in the changes of balance. The results of stabilographic research are widely used in supporting the diagnostic process, sport training as well as they are a very useful tool which makes therapeutic effects objective and are used to define the degree of disability. The connection of Virtual Reality Technologies with stabilography gives the unprecedented results. It allows you to carry out the tests which very often require highly professional equipment . Therefore it turns out to be very important to use the parameters of the world artificially created with the use of the Virtual Reality Technology on the ability to keep balance. The purpose of the research was to find the relationship between the parameters that change in the virtual reality (amplitude of scenery movement and type of scenery) and the measured stabilographic parameters (length of the path, the area of the ellipse and the value of the deviation of the location of the centre of pressure).

Material & Methods: The research has been made to define the influence of the type of the virtual reality scenery and it's movement amplitude on the stabilographic values. Five tests were carried out with the participation of a group of 15 students of the Silesian University of technology at the age of 20-26 (8 women and 7 men).

Results: The measurements of the length of the path, the area of the ellipse and the value of the deviation of the location of the centre of pressure – COP - in the sagittal plane were carried out. The average movement velocity of the centre of pressure was also measured. Average values for the whole research group were defined and the time - frequency analysis of the COP deviation was done.

Conclusions: The analysis of the results showed that the type of the used scenery has a significant impact on the length of the support path, area of the ellipse and velocity of COP movement. In the closed scenery, where the patients are located inside a room or close to the objects, it was observed that there has been a greater impact of the amplitude changes on the above mentioned parameters than in an opened scenery where the examined person is placed in a wide open space. There was also observed an effect of counteraction of the system stabilizing the posture to the visual stimuli. The conducted measurements are the first phase of a project, which aim at developing the system enabling research into human motion system with the use of Virtual Reality Technology.

Keywords: body balance • Virtual Reality Technology • impact

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Introduction

Maintaining balance in a standing posture of the body is a very important skill of the human body, which allows to recover the assigned position in space. This is especially important in many sports disciplines such as martial arts, climbing or sports gymnastic. Two systems in our bodies are responsible for that [1]: the system which stabilizes the posture, responsible for counterbalancing the destabilizing power of gravity and inertia, which consists of labyrinth and sensory receptor of the locomotor system, the other one is the stabilizing system connected with the organ of vision, which determines the visual orientation of the position of parts of one's own body. Adequate training of martial arts sportsmen should be focused, among others, on progress of reactions which can help to avoid uncontrolled falls [2,3]. Inappropriately trained sense of balance can lead to serious injuries [3,4]. Stabilography is the science which deals with keeping balance. The most often the forces of the surface reaction are measured in the sagittal and coronal planes and the COP (centre of pressure), the result of the impact of the forces of the surface, is calculated [5]. The length of the path of support is calculated, that is a way covered by the COP, as well as the value of the area of the ellipse comprising the trajectory set by COP. The border of stability is also defined as a line showing the maximum deviation of COP in the support plane which will not cause the fall of the examined person [1]. Until recently, the border of stability was thought to be the support plane [6], however the Heuristic model of human stability [7] assumes that there is an additional margin of safety that means that the area of stability is larger than the support plane.

The results of stabiligraphic researches are widely used in assisting the diagnostic processes, sports training and they are a very useful tool which makes therapeutic effects objective and they are used to determine the level of disability [3,8,9]. All the pathological or functional changes which impair the functioning of the steering system or executive system are reflected in the changes of balance [10]. There are a lot of devices which enable functional estimation of the therapy of the patients with balance disturbances, dizziness or instability [11]. For the needs of stabilographic research a special unit of measurement - BRU™ (The Balance Rehabilitation Unit) - was prepared by Medicaa® in which measurements base on the location of the centre of pressure [12]. There are ten specially prepared tests, which are applied to the patient. The patient undergoes tests with special visual stimuli while measuring the quantitative indicators such as: the border of stability, the length of the support path and the area of ellipse are being measured [13]. The following tests are carried out in standing position: with open eyes, with closed eyes, on the soft ground, while evoking saccadic eye movements, with optokinetic stimulation of the eyes with an object moving from right to left and up and down and visual disturbances in the sagittal and frontal planes [11,13,14]. In order to evoke visual stimuli the Virtual Reality Technology is often used in a form of projection devices like 3D helmets and 3D goggles.

The use of the 3D technology enables high-quality simulation of the real environment and it enables an easy change of the parameters of the moving objects, at the same time customizing the presented model of the 3D world to the needs of the examined person [15]. The results of the therapy with the use of Virtual Reality Technology are comparable to the effects of the conventional treatment [16]. Virtual Reality Technology provides opportunities to customize the diagnostic and therapeutic process, and any change of the parameters of the presented scene is only done by the computer programmer without any physical interaction.

A combination of stabilografic tests with the 2D and 3D movie projection realized by means of Virtual Reality Technology is a very promising method used, among others, in clinical research of the falls of old patients [17], sports training, during the gait analysis in a disordered environment [18] and while diagnosing BPPV (benign paroxysmal positional vertigo) [19] replacing the conventional methods of treatment. A very good place for the stabilographic research in a distorted world is a place called Virtual Cave (Cave system). This technology gives you the possibilities to transfer the user into a virtual world which indistinguishably resembles a real environment. The surroundings created in such a way in fully interactive and the user is able to fully control those interactions. This control is done with the help of a motion tracing system the external controllers. This place provides a reliable representation of the scene and objects move in the 3D space. It allows you to generate moving objects, which make appropriate moves and thus provide appropriate visual stimuli.

The aim of the research is the relationship between the parameters of visual disorders in the virtual world, and the stabilographic parameters measured during these disorders. The influence of the mentioned parameters on the process of maintaining the balance will be also examined.

Material and methods

The test was carried out with the participation of a group of 15 students of the Silesian University of Technology at the age of 20-26 (8 women and 7 men). All selected participants were healthy, with no imbalances, without defects of sight. There were five tests executed in the research: Romberg's test with the 30 second trial (reference test), test in the closed environment, where the examined person was situated in the virtually created room with 5 meters long walls (Figure1), with small and high amplitude of disturbances. Then the next test was done in the opened scenery and the examined person was placed in the open space with small and high amplitude of disturbances (Figure 2). The small amplitude of disturbances was set on 30 cm while high amplitude was set at 45 cm. The disturbances took place in the sagittal plane. In such plane one can observe bigger influence of the visual disorders on the stabilographic parameters, which was noted in earlier tests of the length of the support path and area of ellipse with the participation of a group of 29 students aged between 20 to 25 [20]. All disturbances lasted for 30 seconds, were of sinusoid character of 1Hz frequency and chosen amplitude and consisted in the motion of the scene in the examined plane of a set amplitude. The disturbances seemed to be unreal, such that do not occur naturally, that is why the translation was connected with rotation of frequency 0,5 Hz, which increased their realism. The measurement of the stabilographic values was done with the use of Zebris FDM-S platform determining the length of the support path, the area of ellipse and time values of the component forces of surface reaction in the sagittal and transverse axis. The test was done in the Virtual Cave situated in Silesian University of Technology, Faculty of Biomedical Engineering in a 3D scene, especially designed by the Quazar3D program. The examined person was standing on the stabilographic platform for about 5 seconds and then, at a time chosen at random the disturbances and measurement were switched on simultaneously.

Figure 1. The picture shows the tests in the closed space

Figure 2. The picture shows the tests in the open space

Results

The individual lengths of the support paths, the areas of ellipse and time values of vertical component of ground reaction forces were determined with the help of the computer program designed for the platform Zebris FDM-S. Figure 3 shows a sample report for a person chosen at random.

With the use of the program Matlab the velocity of the centre of pressure COP was calculated (Table 1). All stabilographic values were averaged for the test group and presented in a Table 1 and on the charts there were the following values presented: the length of the support path, the area of ellipse (Figure 4) and those values in reference to the referential test with open eyes (Figure 5) calculated with the following correlation:

Table 1. Averaged values of the length of the support path, the area of ellipse the average velocity of the centre of pressure for the tests in the close and far scenery with high and low disturbances. OO – with open eyes, AP1 close- small amplitude of disturbances, closed scenery, AP2 close – high amplitude of disturbances, closed scenery, AP1 far –small amplitude of disturbances, open scenery, AP2far – high amplitude of disturbances, open scenery.

	OO	AP1 Close	AP2 Close	AP1 Far	AP2 Far
Average length of the path [mm]	447.55	873.19	633.84	577.29	565.35
Standard deviation of length of the path [mm]	167.25	295.16	165.54	303.21	163.45
Average area of the ellipse [mm^2]	118.20	167.35	95.17	117.00	181.35
Standard deviation of area of the ellipse [mm^2]	182.30	179.31	81.69	224.92	403.64
Average velocity of the COP [cm/s]	1.49	2.91	2.11	1.92	1.88
Standard deviation of velocity of the COP [cm/s]	0.56	0.98	0.55	1.01	0.54

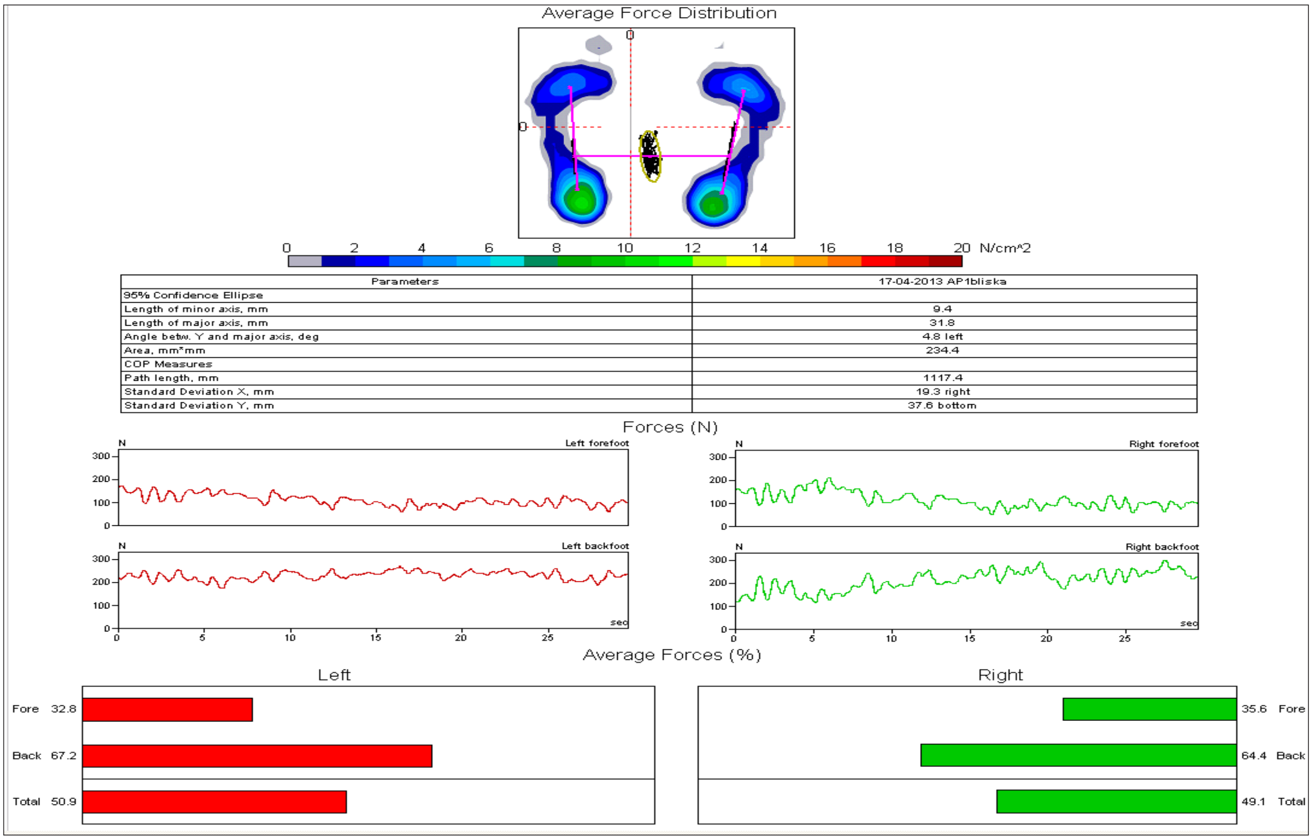

Figure 3. A sample report generated by the program designed for the platform Zebris FDM-S which contains the information about the stabilographic parameters for a person chosen at random. At the top there is a diagram showing the average value of the force distribution generated during the test in the plane of the measuring platform. In the table there are values of stabilographic parameters, and the time charts depict the temporary values of the forces of surface reaction divided into left and right leg, front and back of the foot, the bar charts present the average values.

$$APx/00= \frac{APx - OO}{OO} \circ 100\%$$

Where: OO – the value for the test with open eyes, APx – the value of the parameter for the other tests

The analysis of the position of COP was done in the Matlab program. In reference to van der Kooij's research [21] the values of COP deviation in the sagittal plane was charted (Figure 6) and following McAndrew's researches [18] the frequency analysis of the value of COP deviation in the sagittal plane was made by calculating the Fast Fourier Transform FFT with the use of windowing with Hamming window. The results of the spectrum modulus were averaged for the whole examined group and presented on the spectrogram in Figure 7 for disturbances with small and high amplitude in the open and closed scenery.

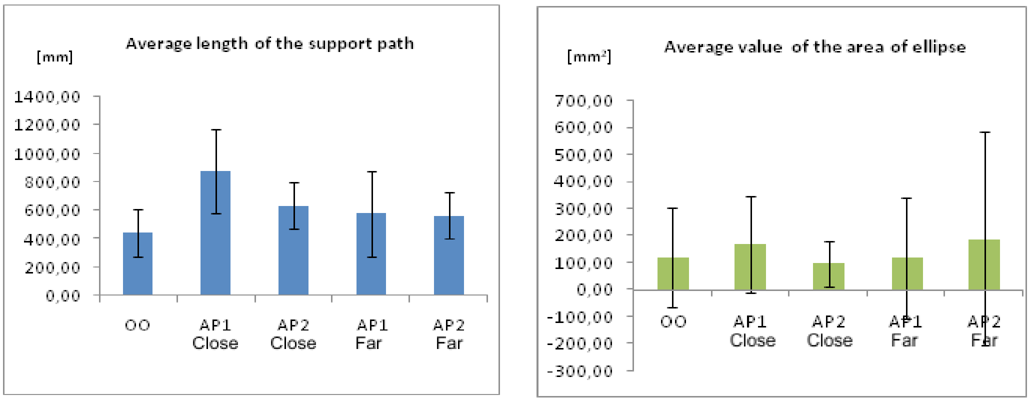

Figure 4. Average length of the support path and the value of the area of ellipse for the test: OO –with open eyes, AP1 close – small amplitude of disturbances, closed scenery, AP2 close – high amplitude of disturbances, closed scenery, AP1 far –small amplitude of disturbances, open scenery, AP2 far –high amplitude of disturbances, open scenery

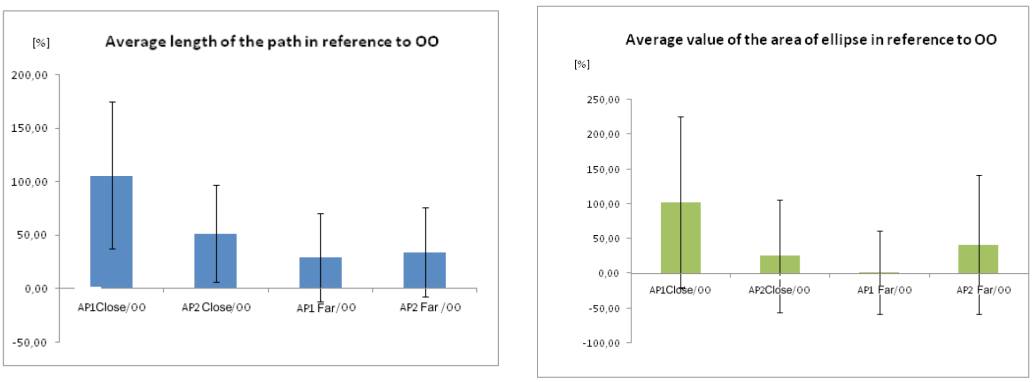

Figure 5. Average length of the support path and the value of the area of ellipse in reference to the tests with open eyes AP1 close/OO –small amplitude of disturbances, closed scenery, AP2 close/OO –high amplitude of disturbances, closed scenery, AP1 close/OO –small amplitude of disturbances, open scenery, AP2far/OO-high amplitude of disturbances, open scenery

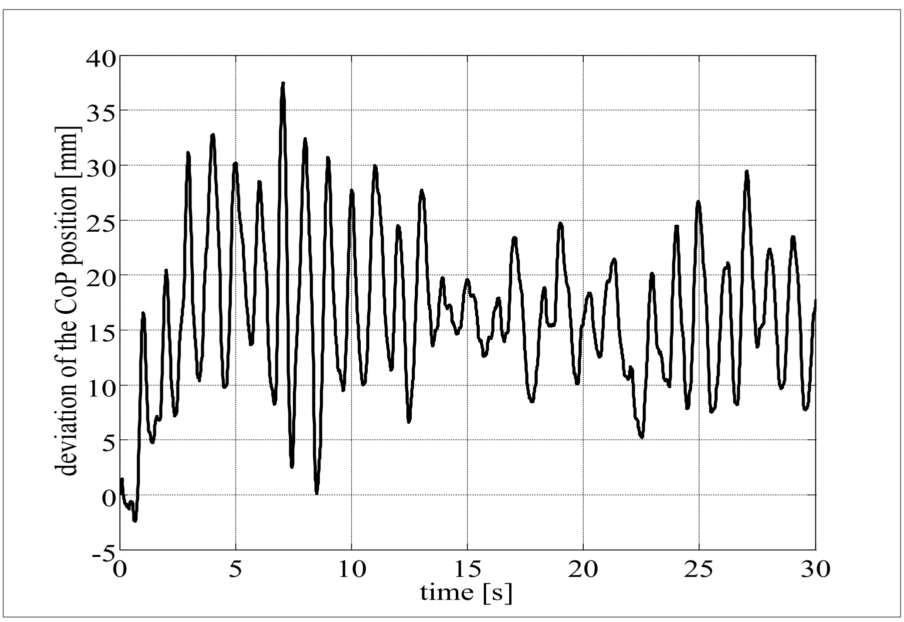

Figure 6. The values of COP deviation in the sagittal plane for a sample person

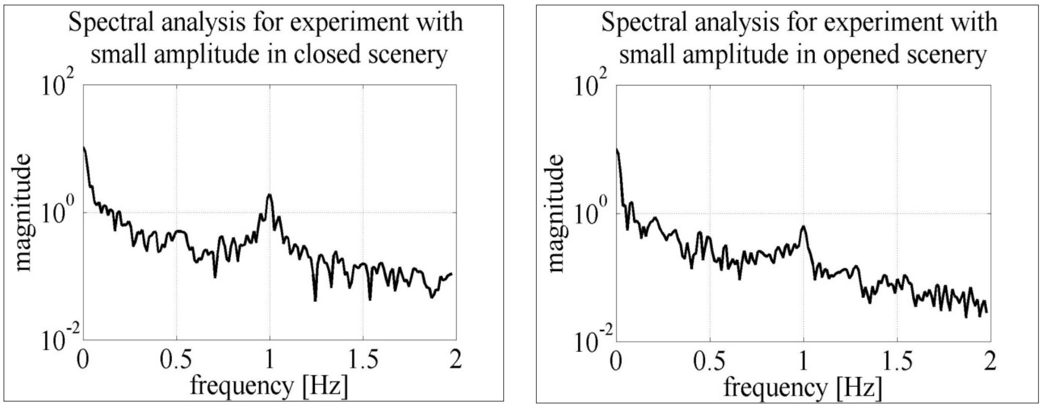

Figure 7. Spectrograms showing the Fast Fourier Transform (FFT with the use of windowing with Hamming window) from the value of COP deviation for the sagittal line for small and high amplitude in the closed and open scenery (quotes on the vertical axis in the logarithmic scale)

A time-frequency analysis was also done by calculating the Short Term Fourier Transform STFT for the values of the COP position deviation in the sagittal plane. A four-seconds span of the window for the Hamming window was taken into consideration, the 0.1 second window shift. The received spectrograms were averaged for each time interval and for the whole examined group and presented in the Figure 8. The arithmetic mean value was calculated for specified time values with the use of the amplitudes of the samples as a function of frequency.

Discussion

The introduction of the disturbances in the sagittal plane increased the velocity of the movement of the centre of pressure in all the experiments similar to Kessler [13]. In the closed scenery, where the examined patient was inside the room that increase was the largest (Figure 5.) and equals more than 100% with the small amplitude of disturbances. Similar effect was noted for the value of the area of ellipse. In the far scenery those changes are several times smaller for the tests with open eyes than in the close scenery. The increase of the amplitude of disturbances in a closed scenery resulted in decreasing almost by half the length of the support path and the average velocity of COP. For the closed scenery there was a reverse result: the increase of the amplitude resulted in increasing the length of the support path in relation to the tests with the open eyes, increase of the average velocity of COP movement as well as the value of the area of ellipse in relation to the test with the open eyes. However those changes are small for the open scenery, and the measured values are comparable The values measured for the average velocity of the centre of pressure, for the tests with open eyes are twice as high as those done by Kessler [13] with the participation of the test group in which the average age was 34.91 ± 13.97. Whereas the value of the area of ellipse was slightly smaller than in Kessler's research [13] and three times smaller than in Kasser's research [19] that included people over 60 with labyrinth disorders. The values of the COP velocity after introduction of disturbances appeared to be twice bigger for the closed scenery and slightly bigger for the open scenery than in Kessler's research [13]. Whereas the average area of ellipse remained three times smaller than in similar tests on people over 60 with labyrinth disorders [19].

The frequency analysis of the averaged COP deviation on the side of frequencies in the sagittal plane showed (Figure 7) distinct influence of the disturbances in the 3D reality on the stabilographic parameters. Similarly like in McAndrew's research [18] there is clear increase in instability that reveals in considerable increase of the value of the component of position deviation of the COP. The increase of this value is as big as frequencies of evoked disturbances in relation to the free body movements. The rest of the components of the COP location in the sagittal plane are considerably smaller (a few dozen or a few hundred smaller except for the fixed component resulting from the permanent displacement of the examined person), and their value decreases along with the frequency, which was also pointed out by McAndrew [18] and Mary Young [22]. For the closed and open scenery at the disturbances with high and small amplitude there is clearly visible band of 1 Hz frequency (Figure 7), the frequency that is correspondent to the frequency of disturbances evoked with the use of virtual reality. The experiment proved the earlier theoretical assumptions related to the influence of the parameters of visual disorders on

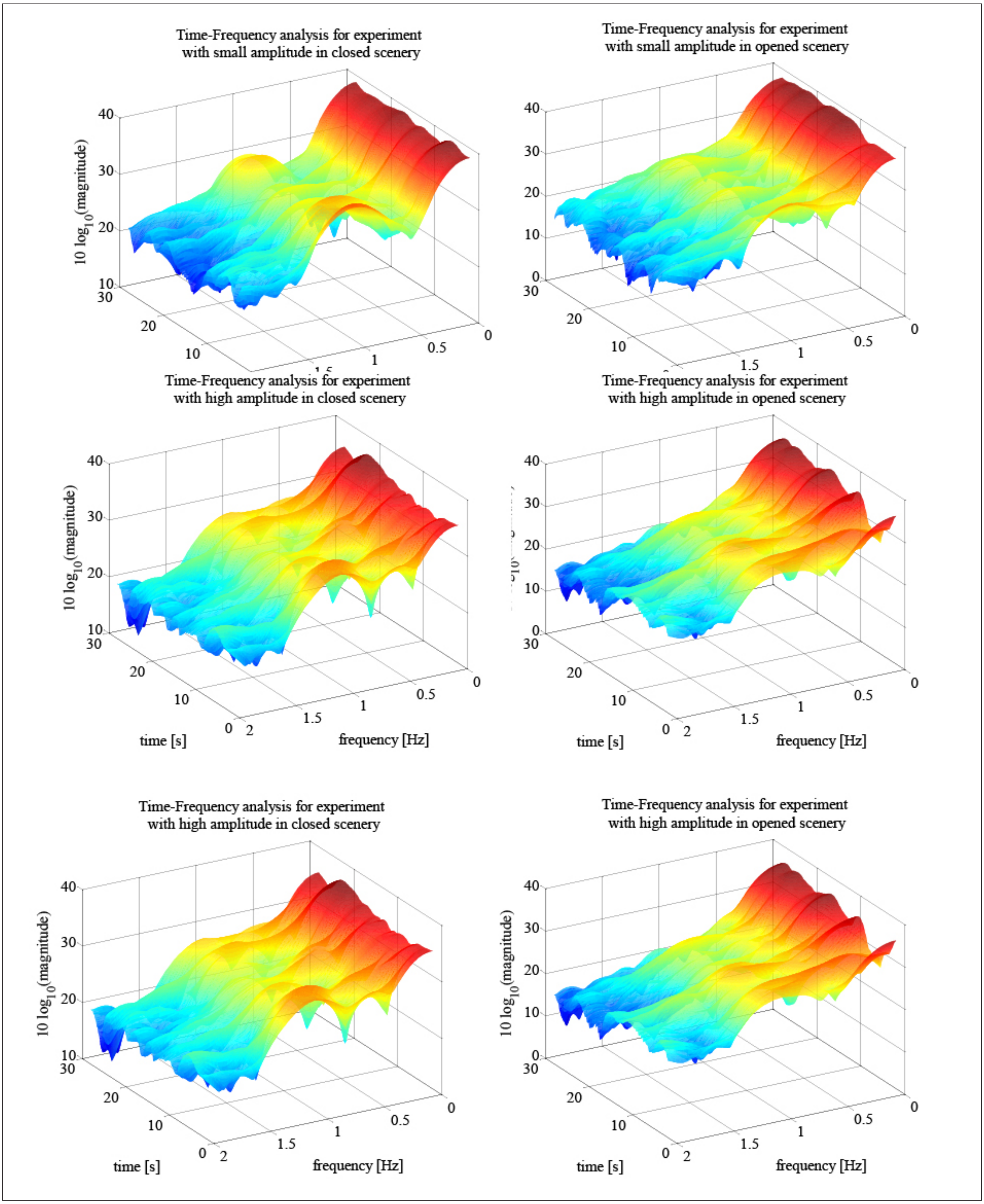

Figure 8. Time-frequency charts that present Short Term Fourier Transform STFT (with the use of windowing with Hamming window) from the value of COP position deviation for the sagittal line for small and high amplitude in the closed and open scenery (quotes on the vertical axis in the logarithmic scale)

the ability to keep balance. The innovative approach turned out to be the time-frequency analysis. On the time-frequency charts (Figure 8) for the 1Hz frequency there can be seen a considerable increase of the value of the COP deviation. While analysing this amplitude in the course of the experiment (from 0 to 30 seconds) we can notice the decrease of that value. The examined person got used to the disturbances that are inflicted, and her/his system of stabilizing the position learns in time how to partially counteract the destabilizing stimuli. The same effect was observed in both sceneries, regardless of the value of the amplitude of disturbances.

Obtained results confirm that it is possible to simulate balance disorders in virtual reality environment. Improvement of techniques, which help sportsmen to avoid falls or enable doctors to conduct very effective rehabilitation are examples of the practical application of such research. The essential part of such training and research is determination of influence of individual visual disturbances on ability to keep the balance.

Conclusions

By evoking the disturbances in the world created with the use of the Virtual Reality Technology we can impinge on the stabilografic parameters of the examined people. The scenery used in the experiment has a big impact on the length of the support path, the area of ellipse and the velocity of the COP movement. In the closed scenery, where the patient is close to the objects or inside a room, a bigger impact of the change of the amplitude on the above mentioned parameters was observed, than in the far scenery, where the examined person was placed in the big, open space. The biggest influence of the disturbances was observed in the first phase of the test, in time the system of stabilizing the position learned how to partially counteract the destabilizing visual stimuli. This effect which has been observed is not completely described in publications. The time-frequency analysis enabled evaluation of the influence on the process of maintaining the body balance. This knowledge can be used in measurements, rehabilitation and exercises based on stabilographic methods. Awareness of possible getting used to one frequency of disturbances and on line time-frequency analysis will enable such adjusting of this parameter, that the patient response will be still at the same level.

Obtained results show how Virtual Reality Technologies can be used both in sports training focused on effective control of body stability and in rehabilitation and treatment. The stabilographic measurements during virtual situations which can potentially cause loss of balance or fall are planned to carry out in the next stage of research.

References

1. Bałaszczyk W, Czerwisz L: Stabilność posturalna w procesie starzenia. Gerontologia Polska, Warszawa 2005 [in Polish]
2. Kalina MR, Jagiełło W, Barczyński BJ: The method evaluate the body balance disturbation tolerance skills - validation procedure of the ‚Rotational Test'. Arch Budo 2013; 9: 59-80
3. Juras G, Rzepko M, Król P et al: The effect of expertise in karate on postural control in quiet standing, Arch Budo 2013; 9: 205-209
4. Kalina MR, Barczyński BJ, Kulkowski K et al: The method to evaluate the susceptibility to injuries during the f all – validation procedure of the specific motor test. Arch Budo 2011; 7: 203-216
5. Strzecha M, Knapik H, Baranowski P et al: Stabilność i symetria obciążania kończyn dolnych w badaniu dwuplatformową wagą stabilograficzną, Jerzy Mosiewicz ed: Czynniki ryzyka i profilaktyka w walce o zdrowie i dobrostan, Lublin 2008 [in Polish]
6. Maki BE: A posture control model and balance test for the prediction of relative postural stability. IEEE Trans Biobed Eng 1987; 10: 797-810
7. Bałaszczyk W. Biomechanika kliniczna. PZWL, Warszawa 2004 [in Polish]
8. Baratto L, Morasso P, Re C et al. A new look at posturographic analysis in the clinical context: sway-density vs. other parameterization techniques. Motor Control 2002;6: 246-270
9. Rynkiewicz T, Żurek P, Rynkiewicz M et al: ability to maintain static balance depending on the engagement of visual receptors among the elite sumo wrestlers. Arch Budo 2010; 6: 149-153
10. Dyszkiewicz A, Opara J: Znaczenie posturometrii i stabilografii w rehabilitacji i zapobieganiu upadkom u osób po udarze mózgu, Zeszyty metodyczno-naukowe pt. Nowoczesna rehabilitacja po udarze mózgu, AWF Katowice 2006: 127-140 [in Polish]
11. http://www.medicaa.com/ (accessed June 30, 2013)
12. BRUTM. Unidade de Reabilitação do Equilíbrio. Manual do usuário. Versão 1.0.7. Versão do Software: 1.3.5.0. Uruguai: Medicaa, 2006 [in Spanish]
13. Kessler N, Ganança MM, Ganança FC et al: Balance Rehabilitation Unit (BRUTM) posturography in relapsing-remitting multiple sclerosis. Arq Neuropsiquiatr 2011; 69(3): 485-490
14. Kasse AC, Santana GG, Scharlach CR et al: Results from the Balance Rehabilitation Unit in Benign Paroxysmal Positional Vertigo, Braz J Otorhinolaryngol 2010; 76(5): 623-629
15. Cikajlo I, Matjačić Z. Advantages of virtual reality technology in rehabilitation of people with neuromuscular disorders. Institute for rehabilitation, Advances in Biomedical Engineering Republic of Slovenia; 2009
16. Cikajlo I, Rudolf M, Goljar N et al. Continuation of balance training for stroke subjects in home environment using virtual reality, International Journal on Disability and Human Development 2011; 10(4): 317-320
17. Duque G, Boersma D, Loza-Diaz G et al: Effects of balance training using a virtual-reality system in older fallers, Clin Interv Aging 2013; 8: 257-263
18. McAndrew P, Dingwell J, Wilken J: Walking variability during continuous pseudo-random oscillations of the support surfaceand visualfield. J Biomech 2010 May 28; 43(8): 1470-1475
19. Kasse C, Santana G, Scharlach R et al. Results from the Balance Rehabilitation Unit in Benign Paroxysmal Positional Vertigo. Braz J Otorhinolaryngol 2010; 76(5): 623-9
20. Wodarski P, Gzik M, Michnik R et al. Możliwości zastosowania wirtualnej technologii 3D w diagnostyce i rehabilitacji na przykładzie badań stabilograficznych. Postępy Inżynierii Biomedycznej 2013: 127-132 [in Polish]
21. Van Der Kooij H, van Asseldonk EHF, Geelen J et al. Detecting asymmetries in balance control with system identification: first experimental results from Parkinson patients. J Neural Transm 2007; 114: 1333–1337
22. Young PM: Dynamic stability of human walking during perturbations and voluntary gait changes. Ph.D. Thesis. The University of Texas at Austin; May 2011

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