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The influence of the acoustic stimulus on postural stability

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Purpose: The purpose of this study was to assess if 65 dB and 4000 Hz stimuli affect postural stability of young normally hearing people. *Methods*: Posturography examinations belong to clinical tests which evaluate the motor skills. Posturography can be divided into static posturography and dynamic posturography. In both static and dynamic posturography patient stays on the platform with opened and closed eyes, but in the case of dynamic one, platform is unstable. In this study the Multitest Equilibre platform produced by FRAMIRAL was used. Patients took part in tests with opened and closed eyes, on stable and unstable platform. Additionally, patients were exposed to 65 dB and 4000 Hz acoustic stimuli. The sound pressure level, and frequency was belonging to the best audibly frequency range. *Results*: Parameters such as velocity and surface were examined. The difference between velocity measured with acoustic stimuli and without acoustic stimuli was observed. On the other hand there was no difference in surface results. *Conclusions*: The statistically significant difference between velocity of patients center of gravity movements, measured on unstable platform, in the presence of 4000 Hz, 65 dB acoustic stimulus and without additional disturbances was observed.

Key words: *postural stability, sound stimulation, static posturography, dynamic posturography*

1. Introduction

The balance mechanism is responsible for the following tasks: delivery of information on body's orientation in space, the direction of movement and velocity, reaction which prevent the fall and stabilize the center of gravity of the body to the equilibrium position. The last task is to control the eyeballs' movements of a person in motion in order to sustain the proper image of the surrounding space [2].

Posturography examinations belong to clinical tests which evaluate the motor skills. Proper position is necessary to handle some daily life tasks and locomotion [2]. The purpose of position evaluation is to define if the patient is prone to falls.

Posturography is a method allowing detection and next treatment of balance disorders. It is a complex examination and consists of few procedures that allows registration and analysis of patients reactions responsible for maintaining the body balance [2]. It also enables the assessment of progress of the rehabilitation [10]. Posturography examination also can be used in idiopathic Parkinson's disease (IPD) and is useful to distinguish fallers from non-fallers [5]. Among other programs of posturography presenting the results of rehabilitation is balance training. The balance training consist of 6 tests: eyes opened test, eyes closed test, target practice, pursuit, one-leg-test and foam cushion. Patients' condition is assessed using all of them. Higher scores during further measurements proves that rehabilitation is effective. Usually the posturographic platform has dimensions 50 × 50 cm and contains tensometric sensors recording force of pressure and moment of this force. Both parameters are the results of the patient's foot pressure on the platform's surface. Results of this procedure can be observed on the monitor [9]. The center of gravity

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(COG), which is the determinant of balance, is located at the height of the lumbar vertebrae. The vertical projection of the COG, which is main component of the center of pressure (COP), can be observed and should be located in the boundaries of foot support. Movements of the body parts affect the COG position. Posturography can be divided into static and dynamic one. During static posturography patient stays on the platform with opened or closed eyes. Surface of the platform can be also unstable when, for example, a pillow is placed on the platform. During examination arms of the patient are located alongside the body. At the time of the examination, the sight of patient should be directed straight ahead. It is also important that the patient cannot be touched during examination. Every touch makes it necessary to repeat the test. Results of posturography have the form of statokinesiograph. Posturography examinations do not require any preparation and deliver information such as path length, velocity or sway area. Second type of posturography is dynamic posturography. During measurement of dynamic posturography patient takes part in tests of the static posturography and next dynamic posturography tests. Dynamic posturography reflects situations that can happen during normal, daily activities. This type of posturography consists of sensory organization test (SOT) and motor test (MCT) [9], [19]. SOT allows to evaluate the maintenance of balance during stimulating of sense organs responsible for posture control. The patient takes part in six tests where balance control system is assessed. Second test, MCT, allows to evaluate correct movements in situations where the patient is subjected to convolution or shift of the platform [19]. Diagnostic capabilities of the platform increase if the platform move in sagittal plane and frontal plane.

The effect of BMI on computer dynamic posturography was tested on a group of 100 healthy women. The study presented no significant correlation between the deviation of the COG and BMI. One of the analysis of the sensory organization test was Motor Strategies test (MS). The MS significantly depended on the BMI of the subject. When the BMI increased Motor Strategies decreased. Dependence between the sensory system and the motor system are determined by subjects height and BMI [15].

Balance control system includes integrated vestibular, visual and somatosensory inputs [9]. Vestibular sensory system, which contains five receptors: two macular (saccule and utricule) and three canalar (lateral, posterior and superior), controls upright posture and vision stabilization. This system can be evaluated with caloric and rotatory tests which indirectly assess lateral canal [6]. Registration of vestibular evoked myogenic potential on sternocleidomastoid (cVEMP) or extraocular muscles (oVEMP) can be also used to assess saccule condition [4].

Vestibular activation induced by the high intensity acoustic stimuli was firstly carried out for animals and described by Tullio and Zanzucchi [23]. The same effect was also observed for humans. For patients with pathological contiguity of tympanoossicular chain and membranous labyrinth [3] or dehiscence of superior semicircular canal [13] vestibular signs and symptoms like vertigo, nystagmus, oscillopsia or postural instability after exposition to loud sound was discovered. Pathological body sways induced by a low-frequency stimulus for patients with Ménière disease and sudden deafness were also observed [8], [18].

Reactions evoked by high intensity acoustic stimulus, such as electromyographic potentials in sternocleidomastoid muscles [4] caused by saccule vestibulo collic reflex [22], were observed for healthy subjects. Contraction of other muscles: soleus and anterior tibial muscles was also described [24]. These reactions can affect postural stability and can be registered during posturography examinations.

Postural instability evoked by low-frequency acoustic stimuli, for healthy patients, have been researched by Russolo [17] and Alessandrini et al. [1]. The increased sways with low and middle frequencies in lateral plane in closed eyes conditions were observed. Postural responses were also registered for laterally-moving white noise of 50 dB_{HL} loudness [21]. On the other hand, according to Mainenti et al., there is no influence of acoustic stimuli on postural stability [11]. Study on the effect of type of music on postural stability were carried out as well [7].

The aim of this study was to assess if the 4000 Hz 65 dB stimulus affects postural stability of young normally hearing people with no vertigo or balance disorders. The purpose was to determine which one of the parameters obtained during posturography examination is the most sensitive to acoustic stimuli.

2. Materials and methods

Thirty healthy volunteers (10 males and 20 females) aged 20 to 35 years old have been participating in this study. All subjects were right-handed, with no self-recorded orthopedic or neurological problems. Most of the participants (21) had body mass index (BMI) 18.5 to 24.9 (Healthy Weight), 7 patients had BMI 25 to 29.5 (Overweight). There were also one person with

BMI under 18.5 (underweight), and one with BMI up to 40 (obesity). The inclusion criteria were: no medication taken on a regular basis and no history of vertigo or balance disorders. Two of patients reported exposure to toxic substances in work environment. Three subjects complained about episodes of tinnitus in the past but none of them suffered from it during research. All of participants underwent audiological evaluation. Pure tone audiometry was carried out. Hearing threshold for air conduction at frequencies 0.125 to 8 kHz was assessed using Inventis Piccolo audiometer and THD-39 headphones. Average hearing threshold was calculated according to WHO, 1997 standards. Patients with hearing loss were excluded from the study.

Fig. 1. Multitest Equilibre platform produced by FRAMIRAL

During carried out researches postural stability was measured with Multitest Equilibre platform produced by FRAMIRAL (Fig. 1). This platform can be used for both static and dynamic posturography. During exams, it was possible to perform measurement for eyes opened and eyes closed. These tests can be carried out also on stable (static) and unstable (dynamic) platform. During the measurement patient had arms alongside their body and looked ahead. Multitest Equilibre platform was surrounded by crash barrier. It was helpful in situations when patient begins to waver preventing them from falling down from platform.

The first operation to be carried out on posturographic platform is to put patient personal data up. Next subject gets on the platform. The platform software consist of three components: Checkup, Rehabilitation and Feedback. Checkup program allows to execute measurement on stable and unstable platform, with opened eyes, closed eyes and with optokinetic stimulus. This program allows to setup the platform. It can be done automatically or manually. The Multitest Equilibre platform permits to use optokinetic stimulus. It was possible to select the angle of rotation of the optokinetic stimulus applicator. Each of the parameters of the stimulator (angle, direction and velocity) can be controlled.

Multitest Equilibre platform also contains a laser pointer. Settings of the platform allows to start up the laser, because as it appears, the light point is helpful to the patient. During measurement patient can look at it.

Next program of Multitest Equilibre platform is Rehabilitation. It allows rehabilitation of the patients after accidents. This program allows to make exercises with unstable platform which at any moment can be shifted at different heights and different angles. Rehabilitation program consist tests: Incline Plane, Fall Prevention, Impulse Rehabilitation and Otholitic rehabilitation. For example, during Otholitic rehabilitation the test platform is unstable and moves up and down. The parameters can have variable intensity and latency (frequency of the impulsion). The last of the programs is Feedback which allows to use the platform to play games. They can be run at static and dynamic platform. An example of such game can be 3D-Crowd Simulator. This simulator presents situation when patient is surrounded by people. The task of the patient is to circumvent as many people as he can. Parameters like exercise duration, passers density or patients size can be set before test.

In this study posturography without acoustic stimuli with eyes opened and closed was carried out first. Next tests were repeated for 65 dB_{HL} 4000 Hz tone presented monaurally to the right ear (consistent with dominant hand of subject). The sound pressure level was equal to normal conversational loudness level, and frequency was belonging to the best audibility frequency range. Acoustic signals was generated by Inventis Piccolo audiometer and delivered byTHD-39 headphones.

In posturography for measurement the Checkup program was used and such parameters as stability rate, velocity and surface were recorded. Reports present on the monitor display both stabilographs – for stable and for unstable platform. The recording period was 30 seconds for each test. Interval between each test was 15 seconds.

Shapiro and Wilk test for normality for all of data sets and Wilcoxon two-sample test for results parameters measured in presence of acoustic signal and without additional disturbances were carried out.

All procedures performed in studies involving human participants were in accordance with the ethical standards of the Bioethical Committee Research and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

3. Results

The improvement in postural stability in the presence of acoustic stimulus for healthy subjects was noticed. The average surface of the patients COP movements was analyzed (Fig.2). Average surfaces registered in the open eyed acoustic stimulus, static and dynamic tests were smaller than in closed-eyed acoustic stimulus, static and dynamic tests. Surface in the closed-eyed, no acoustic stimulus, dynamic test also increased. Only in the closed-eyed, no acoustic stimulus, static test the surface decreased. Values of surface registered using dynamic platform are greater than registered using static one. Average surfaces registered in opened- or closed-eyed, acoustic stimulus, static or dynamic tests, were smaller than in the opened- or closed-eyed, no acoustic stimulus, static or dynamic tests.

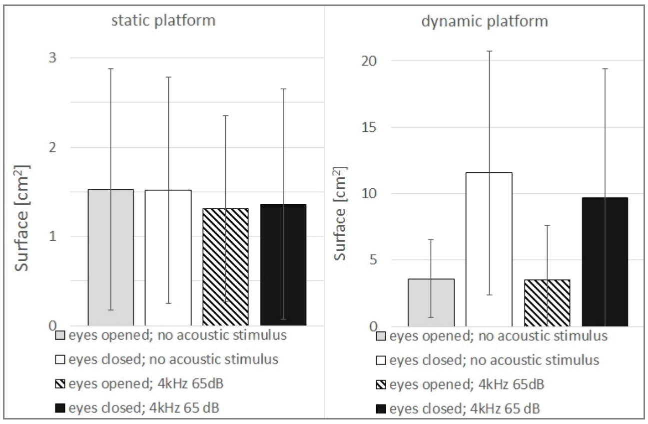

Fig. 2. Mean values of surface of the patient's COP movements

The average velocity of the patients COP movements was also analyzed (Fig. 3).

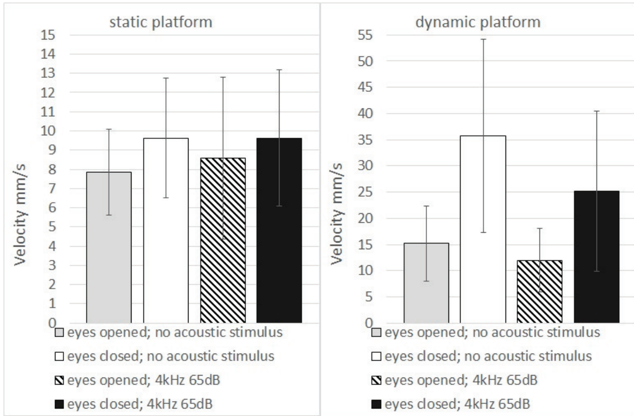

Fig. 3. Mean values of the velocity of the patients' COP movements

The average values of velocity in the opened-eyed, acoustic stimulus or no acoustic stimulus, static and

Table 1. Results of Wilcoxon test for surface of the patients projection of the COG. Parameters measured for 65 dB 4 kHz stimulus were paired with the ones measured in the absence of additional stimuli

Wilcoxon test parameters	platform stable, eyes opened	platform unstable, eyes opened	platform stable, eyes closed	platform unstable, eyes closed
N (sample size)	27	30	27	29
p-value	0.421	0.349	0.337	0.163

Table 2. Results of Wilcoxon test for average velocity of the COG movement. Parameters measured for 65 dB 4 kHz stimulus were paired with the ones measured in the absence of additional stimuli

Wilcoxon test parameters	platform stable, eyes opened	platform unstable, eyes opened	platform stable, eyes closed	platform unstable, eyes closed
N (sample size)	28	26	26	30
p-value	0,569	**0,006***	0,819	**0,001***

* statistically significant difference.

dynamic tests were smaller than in closed-eyed, acoustic stimulus or no acoustic stimulus, static and dynamic tests. Values of velocity registered using dynamic platform are greater than those registered using static one. Mean velocity in the no acoustic stimulus tests were smaller than in the acoustic stimulus tests.

The Shapiro–Wilk test was used to evaluate a normal distribution. None of the parameters correspond to Shapiro–Wilk test. Wilcoxon test was carried out, obtained parameters are presented in Tables 1, 2.

The p value and significance threshold $\alpha = 0.05$ was compared. Only for velocity measured on unstable platform for both tests, eyes opened and eyes closed, a significant dependence occurred.

The study was carried out on a group of thirty volunteers (10 males and 20 females). For all of the subjects BMI was calculated and presented in Table 3.

Table 3. The number of people for each BMI

BMI	Number of people
<18.5 (underweight)	1
18.5–24.9 (healthy weight)	21
25–29.5 (overweight)	7
>29.5 (obesity)	1

The Shapiro–Wilk test was used to evaluate a normal distribution. None of the parameters correspond to Shapiro–Wilk test. Mann–Whitney U test was carried out. There was no correlation between such parameters as velocity of the COP movement or surface of the patients COP and subjects BMI.

4. Discussion

Results obtained in the study on difference between surface, which is determined by COP of the patient with opened and closed eyes, showed deterioration of the surface for closed eyes test, for both, stable and unstable platform. Deterioration of the surface was also obtained in the studies on the surface of stabilogram in children with cerebral palsy, in frontal and sagittal plane. It was tested on a group of 31 patients with cerebral palsy and group of healthy children as a reference group. Closed eyes exacerbated scores of surface in all children. The surface also was measured by Zajdel et al. in group of 40 adult patients after ischemic stroke. It was measured with eyes opened and eyes closed and, next, compared to results of healthy patients. Higher values of surface for patients after ischemic stroke than in group of healthy patients during opened eyes measurement was observed. Closing eyes caused even greater values of surface than for healthy patients, which confirms the conducted research [16].

In the present study, the dependence between postural stability parameters (velocity and surface) and BMI was assessed. The study showed no correlation between postural stability parameters and BMI. Such results were also obtained in the study about the effect of BMI on postural stability in a group of 100 healthy women. The results presented no significant correlation between the deviation of the COG and BMI [15]. Postural stability and weight of the patients were also measured by McGraw et al. Obese subjects obtained statistically significant difference – greater sway area [12]. In our study the surface dependence on BMI obesity cannot be concluded, because only one subject had BMI about 40.

Values of surface and velocity measured with unstable platform were higher than ones measured with stable platform. Obtained results are consistent with several reports. For example Cohen et al., Shahal et al. and Mirka and Black obtained higher values of posturographic parameters measured with dynamic platform [2], [19], [14].

Evoked by acoustic stimulus vestibular reactions such as electromyography potentials, registered in lower-limb muscles were measured for healthy subjects by Watson and Colebatch. Therefore, it is assumed that these reactions can be registered as body sways in posturography examination [24]. In the present study a statistically significant difference between velocity in dynamic tests measured in presence and absence of acoustic stimulation for healthy subjects was observed, which is consistent with Watsons et al. research.

In presented research the improvement is stability – decrease of the patients' COP movements velocity in the presence of acoustic stimulus was observed. The previous studies show increased sways measured for healthy subjects. For example, Russolo carried out research in a group of 20 normal subjects. The 118.5 dB, 500 Hz tonal stimulus was applied monaurally and elicited postural responses measured in both cases, with eyes open or closed the conditions were registered. Postural responses were not observed with a tone of 2000 Hz [17]. Allessandrini et al. analyzed sound – evoked postural responses as well. Forty healthy subjects, aged 29.3 were tested, first without acoustic stimuli, next in the presence of 130 dB, 500 Hz stimuli applied monaurally. The increase of mean velocity in the presence of stimuli, in closed eyes condition was noticed [1], [17]. Results obtained by Allessandrini et al. and Russolo are inconsistent with our observations.

Presumably that difference is caused by the considerable difference in intensities of applied stimuli.

The study on influence of sounds on posture control was carried out also by Siedlecka et al. In their study white noise, sinusoidal and tonal signals were used. However only the 4000 Hz stimulus caused the improvement of postural control, in their study higher sound pressure level (85 dB) than in our study was used [20].

Improved balance can be the effect of more precise and effective usage of proprioceptors and of patients' concentration affected by acoustic stimulation. Wierzbicka-Damska et al. examined a group of children with hearing disorders and, as a reference, a group of normally hearing children. Children with hearing loss obtained better results in postural stability measurement. They conclude that it is result of compensation of vestibular input disturbance by more efficient proprioceptors usage [25].

Concluding velocity of the patients COP movements is the most sensitive to acoustic stimulation parameter. Our observations are consistent with the above-mentioned Allessandrini's et al. research which shows significant difference for absence and presence of acoustic stimulus only for velocity in opened eyes examination [1].

5. Conclusions

Acoustic stimulus with 4000 Hz and 65 dB causes the reduction of patients COP velocity on unstable platform – sound stimulation improves postural stability of young normal hearing subjects without vertigo or balance disorders. The velocity of patients COP on unstable platform is the most sensitive to acoustic stimulation parameter, for both, opened and closed eyes conditions. Exposition to 65 dB and 4000 Hz acoustic stimuli does not affect differences in velocity on stable platform. No statistically significant difference in surface of subjects COP movements evoked by acoustic stimuli occurred. There is no statistically significant correlation between subjects' BMI and postural stability. Presented results can be used as reference values in balance disorders affected by vestibular pathologies diagnosis.

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