


## ORIGINAL RESEARCH

# The effects of acoustic and optokinetic stimulus on the postural stability

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**Abstract**

**Objectives:** This article addresses the question of whether the simultaneous auditory and optokinetic stimulation affects the postural stability differently than only the stimulation with a single auditory or optokinetic stimulus.

**Methods:** The study involved 30 volunteers. The postural stability was evaluated by means of the posturography platform, which allows for both stable and dynamic posturography tests as well as for applying optokinetic stimulus. Three series of measurements were performed in each patient: measurements on an only with the optokinetic stimulus, measurements using only the acoustic stimulus, and finally measurements with both stimuli applied simultaneously.

**Results:** The results indicate that there are statistically significant differences in the findings obtained with the simultaneous auditory and visual stimulation and the observed results with only one of the stimuli on the dynamic platform. Hence, on the basis of the results obtained, it is possible to conclude that the acoustic stimulus has the potential to help maintain a stable posture. However, this process is not sufficiently compensated with the optokinetic stimulation alone.

**Conclusion:** The sense of sight may be essential for the maintenance of a stable posture. The presence of a sound stimulus improves the postural stability, although this improvement does not compensate for the disturbance caused by the optokinetic stimulus. Hence, functioning of auditory and visual system can influence patients posture.

**Level of Evidence:** 4

**KEYWORDS**

hearing, optokinetic stimulus, postural stability, posturography, vision

All the authors contributed equally to this study.

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## 1 | INTRODUCTION

The primary objective of the balance system is to maintain a stable posture simultaneously allowing efficient and safe movement. In order to maintain balance, it is necessary to keep the body's center of gravity, that is, a center of pressure (COP) in the area bounded by the outline of the feet, within the limits of the support surface. In order to maintain the COP within the limits of the support surface, it is essential to compensate for any deflections of the center of gravity from the equilibrium position.

Proper coordination of the visual, vestibular, and sensory systems, coordinated by the central nervous system, is essential for the correct functioning of the balance system. The information provided by these receptors enables the triggering of reflex reactions in the form of postural muscle contraction.

Posturography provides a quantitative assessment of balance system function. Incorporating posturography into the diagnostic process identifies problems with the vestibular system, both with the saccule and utricle as well as with the semicircular canals. Literature analysis indicates a much higher sensitivity of posturography than other tests, such as caloric tests, or electronystagmography in vestibular dysfunction diagnosis.<sup>1</sup>

The anatomical proximity of the balance and auditory systems, the similarity of the vestibular and cochlear structures as well as their common blood supply may indicate that it is reasonable to look for a reciprocal relationship between a stimulation by a sound stimulus and the postural stability.<sup>2</sup> In addition, responses such as potentials evoked by a high-intensity sound signal have been observed in the electromyographic examination. The formation of potentials is a result of the vestibulospinal reflex.<sup>3</sup> In fact, the above-mentioned reactions have been observed both in the sternoclavicular and mastoid muscles,<sup>4</sup> as well as in the soleus and tibialis anterior muscles.<sup>5</sup>

The first description of balance disorders resulting from a loud sound stimulus on an animal model was developed as early as the 1930s.<sup>6</sup> Similar reactions have also been observed in humans. Symptoms such as dizziness, nystagmus, and oscillopsia have been reported in patients with damaged ossicular chain or superior semicircular canal fistula after acoustic stimulation. Imbalance after exposure to low-frequency sound was also observed in patients suffering from Ménière's disease or sudden sensorineural hearing loss.<sup>7,8</sup>

The literature data on the effect of the acoustic stimulus on postural stability of healthy subjects is inconclusive. At the same time, it is worth emphasizing that the authors use different methodologies for the stimulus presentation. The physical parameters of the applied stimuli differ, and there are also differences in the posturographic platforms used. Posturography test can be performed on a stable, unstable (simulating dynamic conditions), or dynamic platform. In the research studies concerning the effects a sound stimulus has on the postural stability, there have been reports of both significant differences and no differences between the results obtained on a stable and dynamic platform with a simultaneous acoustic stimulation.<sup>9</sup> The patients' age may represent a relevant factor, since a more prominent effect of an additional sound stimulation was observed in older

people.<sup>10</sup> Moreover, it also seems essential for the stimulation to last for a sufficiently long time, with a limit value of 30 s.<sup>2,11,12</sup> The intensity of the stimulus applied also constitutes another key factor due to the fact that an imbalance resulting from an increased activity of the vestibular neurons is observed with an increased sound intensity.<sup>13,14</sup> This effect has also been found in posturography tests. Authors who used sounds with the intensity levels greater than 100 dB<sub>SPL</sub> observed a deterioration of the postural stability.<sup>11,15</sup> Simultaneously, in studies where signals of 60–65 dB<sub>HL</sub> were used, an improvement in the stability was found as compared to the results obtained without the additional sound stimulation.<sup>9,16</sup> Furthermore, too low-intensity levels may not trigger the abovementioned effects. In a study in which a sound level of 30 dB<sub>SL</sub> was applied, no significant differences were observed between the results obtained both with and without the sound stimulus.<sup>17</sup> Interestingly, in a group of visually impaired subjects, the stimulation with even very quiet sounds affects the postural stability.<sup>18</sup> Another parameter of the acoustic signal requiring attention is its frequency. The analysis of the recent literature data has failed to provide a clear explanation as to which frequencies in particular and to what extent influence the postural stability. The analysis of the sway frequency allows the observation of correlations between sound frequencies and sway present at low frequencies.<sup>11</sup> For sound stimulation with frequencies in the range of 500–4000 Hz, there are both reports of improvement<sup>9,19</sup> and deterioration<sup>13,15</sup> of the postural stability when sound is present. Wideband signals have also been investigated in studies on the effects of sound on the postural stability. The results of the studies to date have been inconclusive, therefore, it is suggested that there both are differences due to additional stimulation,<sup>16</sup> and that there are no differences.<sup>17</sup>

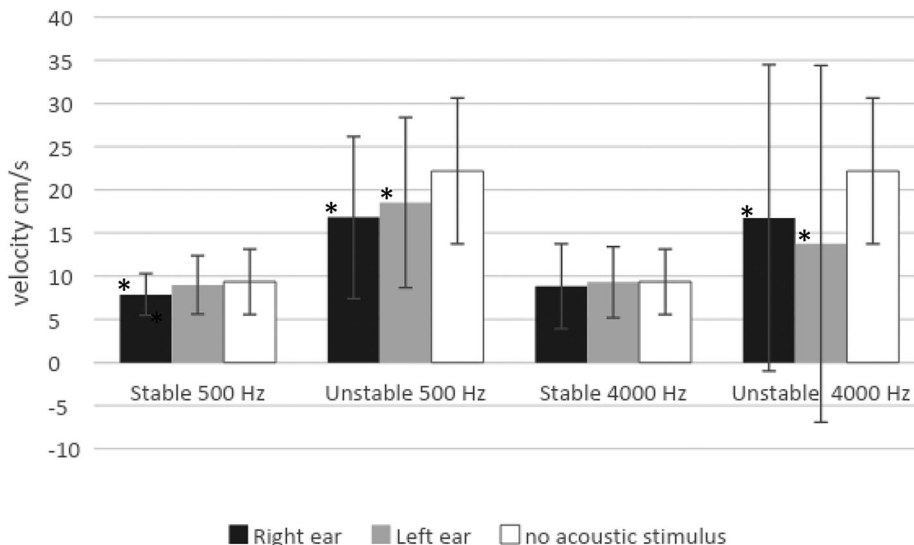
Expanding the posturography test to include a test with an additional optokinetic stimulus may provide valuable information. This test allows for the assessment of the influence of the visual control on maintaining a stable posture.<sup>20</sup> Moreover, the results of the previous studies indicated that the simultaneous use of visual and auditory stimuli may affect the postural stability differently than applying only one type of stimulus.<sup>11,21</sup> The optokinetic stimulus is a standard test in the rehabilitation of vestibular disorders and vertigo.<sup>22,23</sup> Nevertheless, it is worth bearing in mind that a short-term stimulation has a negative impact on the postural stability.<sup>24</sup>

The aim of the present study was to evaluate the effect of a single stimulation with an acoustic stimulus, an optokinetic stimulus, as well as a simultaneous stimulation with both types of stimuli on the postural stability in healthy subjects.

## 2 | MATERIALS AND METHODS

The postural stability was evaluated by means of the posturography Multitest Equilibre Platform produced by Framiral, which allows for both stable and dynamic posturography tests as well as for applying optokinetic stimulus. The dynamic sway of the platform is controlled by the pneumatic pistons connected with a compressor. Moreover, in the aforementioned device, unstable conditions were obtained by

**FIGURE 1** Center of pressure (COP) deflection velocity with and without an acoustic stimulus during the optokinetic stimulation. \*Statistically significant difference between results with and without an acoustic stimulus.



suspending the platform on the springs. The optokinetic stimulus was generated using a full-field visual environment rotator, similarly to the study conducted by Pavlou.<sup>22</sup> Three series of measurements were performed in each patient. (1) Measurements on a stable and unstable platforms only with the optokinetic stimulus. (2) Measurements on a stable and unstable platforms using only the acoustic stimulus, and finally (3) measurements on a stable and unstable platforms with both stimuli applied simultaneously. Each measurement lasted 30 s. Tones with frequencies of 500 and 4000 Hz, and an intensity level of 65 dB<sub>HL</sub> were used as the acoustic stimulus. The sounds were generated by an Inventis Piccolo audiometer and administered monaurally via TDH-39 headphones.

The study involved 30 volunteers (10 men and 20 women), aged between 20 and 35 years of age. All patients were right-handed. The exclusion criteria were any orthopedic or neurological problems or hearing loss. Most patients (21 patients) had a body mass index (BMI) between 18.5 and 24.9 indicating a normal body weight. Several patients were overweight (7 patients) with BMI between 25 and 29.5. One underweight and one obese patient participated as well.

The Shapiro-Wilk test was used to evaluate the normal distribution of the data. Student's *t*-test and Wilcoxon test were performed for a normal and a lack of normal distribution, respectively. The significance threshold was established as  $\alpha = 0.05$ .

The Bioethics Committee approved the study on 11 June, 2015—Resolution No. 535/15. Each participant was informed about the purpose and methodology of the research. Everyone provided informed written consent to participate in the study.

### 3 | RESULTS

#### 3.1 | A comparison of the results with and without an acoustic stimulus during the optokinetic stimulation

The results obtained in the patients during an additional stimulation with acoustic stimuli were compared with the results obtained

without acoustic stimulus during a simultaneous optokinetic stimulation. The median values of COP deflection velocities for stable and unstable posturography are shown in Figure 1.

A comparison of the results on the stable and unstable platform of all stimuli revealed a greater deflection velocity during unstable posturography. Furthermore, the deflection velocity of the COP decreased when the acoustic stimulus was applied.

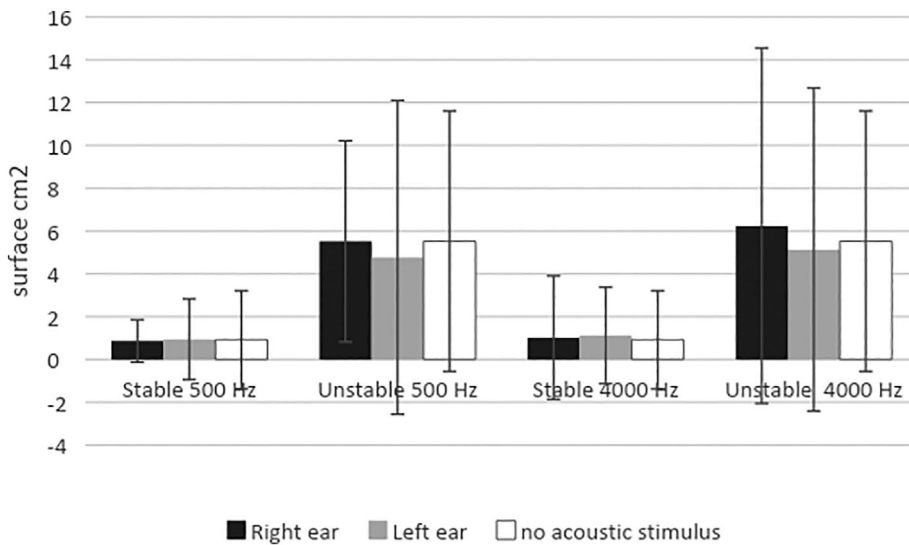
An analysis of the COP sway surface for identical conditions was also performed. The median values of the area covered by the COP for stable and static posturography are shown in Figure 2. In terms of velocity, an increase in the area values is observed on the unstable platform compared to the results obtained on the stable platform.

Statistical analysis was also performed to assess whether the differences between the results obtained with the optokinetic stimulus alone and with a simultaneous acoustic and optokinetic stimulation are significant. The results of the comparison between the effects of one and two stimuli are shown in Table 1. Statistically significant differences were observed for COP deflection velocity during the test on the unstable platform. No significant differences were found in terms of the stable test, the only exception was the difference between the deflection velocity on the stable platform with the optokinetic stimulus on and the deflection velocity on the stable platform with the optokinetic and 500 Hz acoustic stimuli applied to the right ear. No statistically significant differences were found for the COP sway surface.

#### 3.2 | A comparison of the results with and without optokinetic stimulus during the acoustic stimulation

The observed results during a simultaneous stimulation with optokinetic and acoustic stimuli and without additional visual stimulus were compared. The acoustic stimulus applied during the test was identical to the first measurement. Median COP deflection velocities for posturography on the stable and unstable platform are shown in Figure 3.

An increase in COP deflection velocity was observed during posturography on an unstable platform during a simultaneous visual and

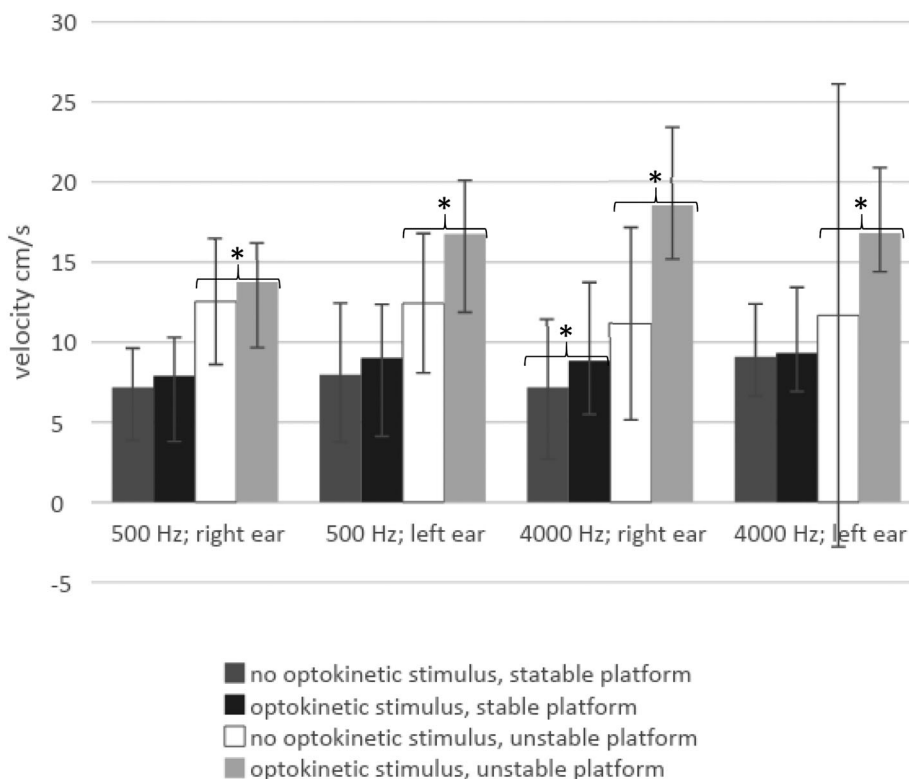


**FIGURE 2** Center of pressure (COP) sway surface with and without acoustic stimulus, during the optokinetic stimulation.

Type of platform	Stimulus	Speed: <i>p</i> -value	Surface: <i>p</i> -value
Stable	Right ear 500 Hz	<.01*	.42
	Left ear 500 Hz	.20	.81
	Right ear 4000 Hz	.83	.39
	Left ear 4000 Hz	.57	.78
Unstable	Right ear 500 Hz	.01*	.58
	Left ear 500 Hz	.03*	.88
	Right ear 4000 Hz	.01*	.54
	Left ear 4000 Hz	<.01*	.33

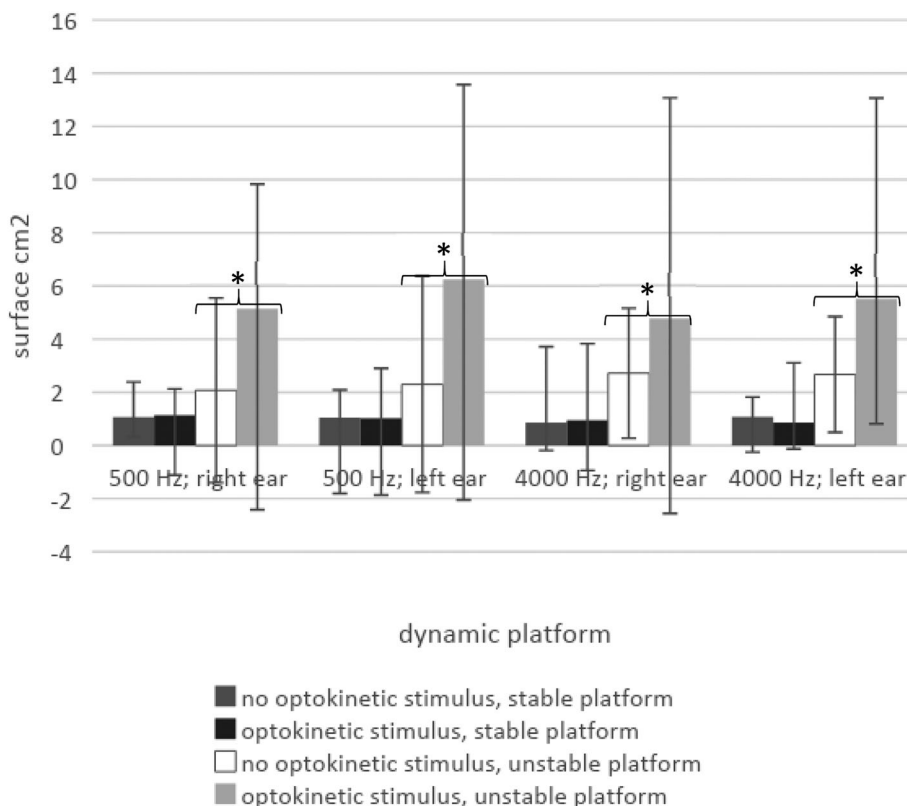
**TABLE 1** The statistical analysis results, a comparison of the results with and without the acoustic stimulus

\*Statistically significant difference.



**FIGURE 3** Center of pressure (COP) deflection velocities with and without optokinetic stimulus, measured on a stable and unstable platform during stimulation with a sound stimulus. \*Statistically significant difference between results with and without an optokinetic stimulus.

**FIGURE 4** Center of pressure (COP) sway surface with and without an optokinetic stimulus, measured on the stable and unstable platforms during a sound stimulus stimulation. \*Statistically significant difference between results with and without an optokinetic stimulus.



**TABLE 2** A comparison of posturography results obtained during the stimulation with an acoustic stimulus and with both the acoustic and optokinetic stimuli simultaneously

Platform type	Stimulus	Speed: <i>p</i> -value	Surface: <i>p</i> -value
Stable	Right ear 500 Hz	.32	.41
	Left ear 500 Hz	.78	.35
	Right ear 4000 Hz	.05*	.37
	Left ear 4000 Hz	.21	.39
Unstable	Right ear 500 Hz	<.01*	<.01*
	Left ear 500 Hz	<.01*	<.01*
	Right ear 4000 Hz	<.01*	<.01*
	Left ear 4000 Hz	<.01*	<.01*

\*Statistically significant difference.

auditory stimulation compared to results obtained with the acoustic stimulus alone. However, such relationships were observed irrespective of lateralization and frequency. The differences observed on the stable are less pronounced than on the unstable platform, although there is still a tendency to increase the deflection velocity when the other stimulus is applied.

The analysis of the values for the COP area was also performed. The medians of the COP area for the static and dynamic posturography are presented in Figure 4. Similarly, to velocity, an increase in the COP sway surface was observed during dynamic posturography, as well as in the course of a simultaneous visual and auditory stimulation in comparison to the results obtained only

with the acoustic stimulus. Simultaneously, no similar tendency was found during the test on a stable platform.

The results of the statistical analysis are presented in Table 2. A statistically significant difference was found between the area defined by the patient's COP during a stimulation with an acoustic stimulus as well as during the stimulation with the acoustic and optokinetic stimuli simultaneously, on the unstable platform. This difference occurs for both frequencies used, regardless of the lateralization of the acoustic stimulus. Similarly, statistically significant differences were shown for COP deflection velocity. Furthermore, for static posturography, statistically significant differences were observed only for the COP deflection velocity when the right ear was stimulated with a

4000 Hz stimulus. For the other stimuli, no statistically significant differences were found.

## 4 | DISCUSSION

For both stimuli, tests were carried out on a stable and an unstable platform. In the tests on the unstable platform, an increase in the values of the sway velocity can be observed. The obtained results are consistent with the findings of Cohen et al., where one of the described studies involved the introduction of a disruptive stimulus while standing on a cushion wearing a visual/vestibular-conflict dome.<sup>25</sup> Similar results were also reported by Mirka and Black<sup>26</sup> as well as Hahal et al., who investigated the effect of seasickness on performance using a dynamic posturography platform. The results revealed a higher susceptibility to somatosensory and visual stimuli in patients presenting with seasickness symptoms.<sup>27</sup>

Studies have shown that during optokinetic stimulation, the application of an acoustic stimulus results in a decrease in the COP deflection velocity (Figures 1–4). This phenomenon was observed at both 500 and 4000 Hz. Moreover, the aforementioned results are consistent with the findings described by Majewska et al.,<sup>9</sup> Siedlecka et al.,<sup>19</sup> and Agaeva et al.,<sup>16</sup> where an acoustic stimulus triggered a decrease in the COP deflection velocity. According to the study by Siedlecka et al., the application of high-frequency sounds resulted in a reduction of the sway. Therefore, it is possible to conclude that a high-frequency sound improves the postural stability.<sup>19</sup> In addition, Aegave and Altman analyzed the effect of a moving sound source on stabilograms and the sway amplitude and they found a reduction in the sway amplitude measured when an acoustic stimulus was present. Simultaneously, in patients who were subject to the acoustic stimulation, minor differences were observed when comparing the amplitudes with their eyes open and closed.<sup>16</sup> Furthermore, the results presented by Majewska et al. indicate a decrease in the sway velocity on the unstable platform following the stimulation with an acoustic stimulus.<sup>9</sup> In all the sources mentioned above, the stimulus intensities ranged between 60 and 80 dB,<sup>9,16,19</sup> whereas in the study described in this article, the intensity level used amounted to 65 dB HL. Thus, we can conclude that the application of an acoustic stimulus with an intensity level of 60–80 dB<sub>HL</sub> improves the postural stability.<sup>9,16,19</sup> The frequencies of the stimuli used in the present study were 500 and 4000 Hz and the same frequencies were used in the studies by Kapoula et al. and Siedlecka et al.<sup>2,19</sup> Nevertheless, different results were obtained by Park et al.<sup>13</sup> and Russolo.<sup>15</sup> According to Park et al., with an increase in the frequency of sound, the postural stability decreases.<sup>13</sup> The same conclusion was reached in the study by Russolo, who found a negative effect of high-frequency sounds on the postural stability.<sup>15</sup> However, it is worth bearing in mind that in both studies the sound intensity levels were much higher—120 dB and 105 dB<sub>HL</sub>, respectively.

The impact sound stimuli exerts on the postural stability may explain the effects of sound on the postural muscle function as observed in the electromyographic tests: Watson and Colebatch demonstrated the formation of potentials in the soleus and tibialis anterior muscles induced by sound stimuli.<sup>5</sup>

An increase in COP deflection velocity and sway surface recorded in posturography on the unstable platform during a simultaneous visual and auditory stimulation was observed in comparison to the results obtained only with the auditory stimulus. The deterioration of the postural stability when a visual stimulus is present is indicated by a study on the effect of the optokinetic stimulation conducted by Blanks et al.<sup>24</sup> However, the study previously conducted by Rumalla et al. indicated that with a visual deprivation, an acoustic stimulus may be helpful in maintaining a stable posture. In their research, tested the postural stability in patients with a hearing loss both in the aided and unaided condition, when Broadband white noise (0–4 kHz, 65 dB) was present. The tests were conducted in the dark.<sup>21</sup>

Our study suggests that this process will not be sufficiently compensated with the optokinetic stimulation—the results observed when both stimuli have been applied are poorer than in a similar study by Majewska et al. on the effect of sound stimuli on the postural stability conducted on the same platform. It is also worth noting that in this study, the effect of sound-induced stability improvement was observed only with the eyes opened,<sup>9</sup> whereas closing the eyes significantly impairs stability and increases the area of COP sway surface.<sup>28</sup> This, in turn, indicates the crucial role of visual information in maintaining a stable posture.

The patients in our study groups presented different BMI values. A previous study developed by Olchowik et al. indicates a correlation between the BMI values and the postural stability.<sup>29</sup> In our study, we primarily focused on the differences, and to a lesser extent on the obtained values of COP velocity or sway surface. Furthermore, outliers have been excluded in the statistical analysis to avoid the influence of the BMI values on the obtained results.

The results of the study can be useful in examining people with visual impairment. One of the most difficult skills to master by blind and partially sighted people is spatial orientation. The sense of balance and proprioception are important in the development of spatial orientation. Especially in the case of blind people, the proprioceptive system, the sense of touch, and the vestibular system enable the development of body awareness, controlling it, and planning movements. In addition, tests using acoustic disturbing stimuli, low and high frequency, can show an effect on maintaining proper body control in this group of people, thanks to the extremely developed deep feeling.<sup>30,31</sup> Posture examination can also be used to assess the likelihood of a fall in people with Parkinson's disease.<sup>32</sup> In addition, in patients with pathologies of the auditory ossicle chain junction and the membranous labyrinth, fistulas of the anterior semicircular canal, Meniere's disease, or sudden deafness.<sup>33–35</sup>

## 5 | CONCLUSION

In order for the balance system to function properly, the central nervous system needs to coordinate the visual, vestibular, and sensory systems.

It has been found that an improvement in the postural stability occurs with the auditory stimulation, whereas a deterioration occurs when the optokinetic stimulation is present. When the synergy of the

two stimuli is used simultaneously, the effect of both elements on the postural stability is observed. On the one hand, poorer results were observed than with the sound stimulation alone, and on the other hand, better results were visible than with the stimulation of the optokinetic stimulus alone. These results indicate that the presence of a sound stimulus improves the postural stability, although this improvement does not compensate for the disturbance caused by the optokinetic stimulus.

In conclusion, the sense of sight may be essential for the maintenance of a stable posture. Nevertheless, research reports on the effects of different stimuli on the postural stability are scarce. Therefore, further research in this area is required, since the ability to maintain balance remains crucial in the development of motor and physical performance.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

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