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EVALUATION OF POSTURAL BALANCE IN CHILDREN WITH NORMAL HEARING USING WII BALANCE BOARD

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Human balance is a multidimensional concept, referring to the ability of a person not to fall. It can be characterized as the potential of the body to maintain a stable posture for maximum time with minimal body sway. Balance is achieved through the integration and coordination of numerous body systems such as audio-vestibular, visual, motor as well as higher-level premotor systems [1].

Information from sensory systems is interpreted in the central nervous system, based on the internal circuit of the body, a response is formed, and postural muscular synergies are activated to perform appropriate movements of the head, eyes, torso and extremities to maintain posture [2].

Balance maintaining involves holding, attaining, or restoring the projection of a center of pressure (COP) relative to the support base, or generally within limit of stability. The limit of stability is the maximum deviation of the body that a person can arbitrarily withstand in any direction without falling or having to take a step [3].

The functions of the balance system include:

1. Maintaining a certain postural position, such as sitting or standing.
2. Promoting voluntary movements such as transitional movements between postures.
3. Reactions that restore equilibrium after sudden external stimuli such as a trip, a slip or a push.

Balance control is essential not only to maintain postural stability, but also to ensure safe mobility in everyday life, such as performing manual tasks while standing, lifting from a chair, walking and turning.

The balance is usually tested on a force platform in a laboratory setting. Force platforms are commonly found in research laboratories, physiotherapy and audiology departments because they can be used to identify most types of balance disorder, are available commercially and have normative data associated with them [4].

During the study, the body sway data, a factor directly related to the balance, is obtained by recording the force vector applied by the body to the plane of the platform. The data obtained allow to accurately describe the body sway using several quantitative indicators.

There are some important limitations. Testing on the force platform is time-consuming procedure, the platform itself requires installation under the floor, which restricts its mobility and significantly increases the overall cost of the equipment. Thus, the classical force platform is difficult to use in conventional clinical practice.

The Wii Balance Board (WBB) device (Nintendo, Kyoto, Japan) is relatively inexpensive and available almost anywhere in the world, but it is potentially effective to perform an instrumental balance assessment in limited time and space clinical settings. This device resembles a typical force platform (Fig. 1), and is a clinically useful tool for assessing balance [5].

Figure 1. The Wii Balance Board

Scientists from several countries are using WBB with adapted or custom software, such as LabView (National Instruments, Austin, TX, USA), Balancia (Mintosys, Seoul, Korea), Wii Posturografie Tomas Bata University, Zlin, Chech Republic) that communicates with WBB via Bluetooth to evaluate differences with laboratory-level force platforms [5-7]. WBB demonstrated excellent concurrent validity in comparison with force platforms to quantify static balance in healthy adults (ICC 0.77 to >0.99) and in patients with Parkinson's disease (ICC=0.92-0.98) after stroke (ICC=0.82-0.98) [8, 9].

All other publications were based on results from laboratory-level platforms. One of the published postural balance studies in healthy children, which examined 127 children aged 3 to 9 years, were performed using the EquiTest ™ Dynamic Posturography Device (NeuroCom, Int. Clackamas, OR, USA) [10]. During the study, 6 tests were performed, each repeated 3 times for 20 seconds. 3 tests out of 6 were conducted on a mobile platform.

The mean of the integral balance indicator, Equilibrium Score, increased linearly as a function of age, although in some cases the increase was not monotonic (for example, one of the indicators aged 7 to 8 years decreased). Compared to the normative data in adults, the integral balance index in children aged 9 years remained below that in adults.

Another study, involving 96 healthy children between the ages of 3 and 6, was performed on a laboratory posturographic platform in four positions (with eyes open and closed, standing on a stable platform and on a platform covered with elastic foam) [11].

The authors made the following conclusions:

- not all 3- and 4-year-olds are able to pass the test with their eyes closed,

- sensory perturbations provoke an increase in postural balance in all preschool children,

- 3-, 4- and 5-year-old children show similar postural balance.

The equilibrium maturation have also been studied through posturography. Shumway-Cook and Woollacott described a transition period of 4-6 years, when the importance of vestibular information in controlling postures is significantly increased, and structural organization of postural synergies is taking place [12]. Another paper analyzed the results of examination of 45 normally hearing children aged 4 to 10 years [13]. The authors conclude that the maturation of structures responsible for the postural balance occurs to age of 7 years. Shams and al. in their study of 800 children aged 2-18 years showed that 14-16 year-old teens are capable of processing, integrating and organizing sensory systems information for postural control like adults [14].

The postural balance in healthy children has not yet been widely studied with the help of WBB, despite its important advantages in mobility and cost. At the time of writing, we found information about healthy children in the main or control group in three articles. The first involved 10 patients with an average age of 13.1 years, the second – 19 patients aged 9-10 years, the third – fifty four 10-14 year-olds [15-17]. Information about normative posturography data in children younger 9 years is scarce.

At the same time, the WBB platform is of great scientific and practical interest for testing various groups of children with existing and possible vestibular disorders, for example, children with sensorineural deafness, after the middle and inner ear surgery, as well as after concussion, sports injuries, in various neurological disorders, accompanied by imbalances.

The purpose of our study was to investigate quantitative variables of postural balance in healthy children using the Wii Balance Board.

Materials and methods

Prospective non-interventional study of children with normal hearing without vestibular complaints, who were referred to the Pediatric outpatient department of the State Institution "O.S. Kolomiychenko Institute of Otolaryngology National Academy of Medical Sciences of Ukraine", Kyiv, Ukraine due to adenotonsillar diseases. Following obtaining the parents' informed consent for the examination of the child we performed otoscopy, tympanometry, acoustic reflexes testing, whisper test and transient otoacoustic emissions (TOAEs) test. In case of obtaining normal parameters (normal otoscopy, tympanogram type A on both ears, acoustic reflexes are registered on both ears, whisper test more than 5 meters on both ears, TOAEs on both sides were present), the child was included in the study. A total of 38 children, aged 3 to 14, were enrolled. The study was in accordance with the Declaration of Helsinki.

The static balance was assessed using a posturography platform Nintendo WBB connected via Bluetooth to a Dell 3550 laptop (Dell Inc, Round Rock, TX, USA). Weight measurement accuracy of WBB with Wii Posturografie software was verified by the state-owned enterprise Ukrmetrteststandart. Postural balance indicators were recorded using Wii Posturografie software (WPS) developed at the Department of Applied Informatics at Tomas Bata University (Zlin, Czech Republic) (Fig. 2).

WPS was specially designed for evaluation of postural stability via WBB. This software calculates series of values which are important to determine the body sway.

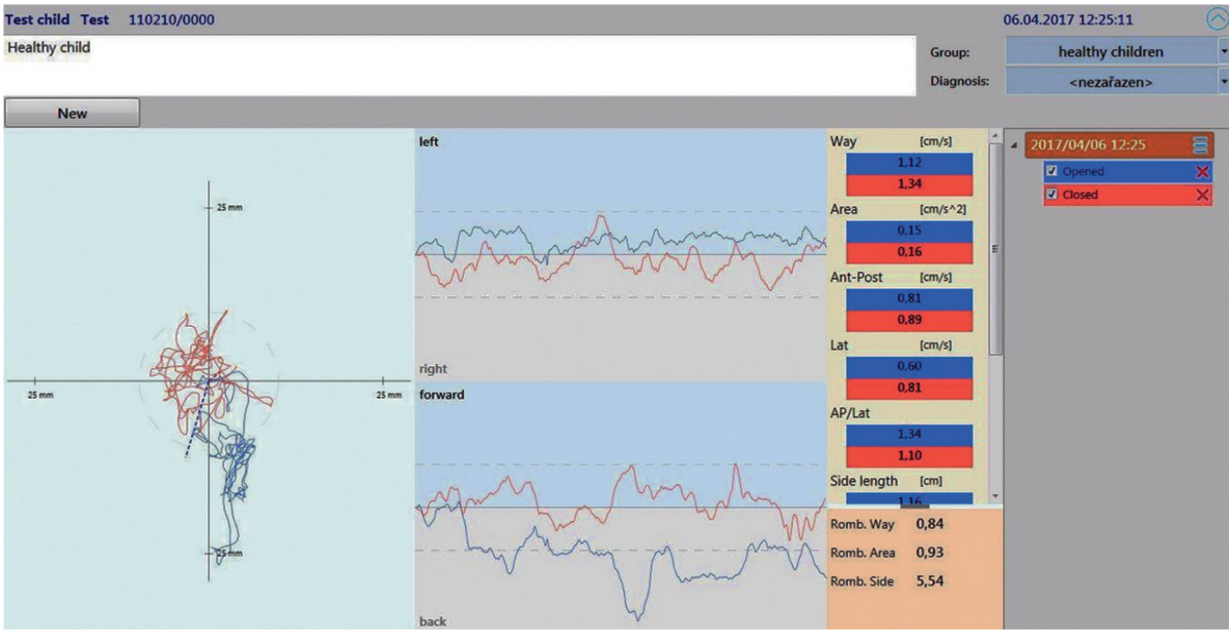


Figure 2. Wii Posturografie Software user interface

The study was as follows. All measurements were performed in quiet clinical office. WBB was calibrated before each patient. The patient barefoot stood on a platform in position with heels together and the toes 30 degrees apart. The child was given sufficient time for adaptation, approximately 30 seconds, then the balance values were recorded in the position with his eyes open for 20 seconds. Next, the child was asked to close his eyes and the balance values were recorded for the next 20 seconds.

All parameters were recorded in two positions: with open and closed eyes. In the first position the vestibular system, visual posture control and the proprioceptive system involved in maintaining the balance. In the second position, the visual control of posture is excluded.

Parameter "Way" (cm/s) describes the path of moving center of gravity, but because the examination time given a constant number, Way is characterized as the velocity of center of pressure (1).

$$M_i = \sqrt{(x_{i+1} - x_i)_2 + (y_{i+1} - y_i)^2} \quad (1)$$

$$W = \frac{T^{-1}}{n} \sum_{i=1}^{n} M_i [m \quad / s],$$

where:

Mi – particular element of way calculation

T – measure period [s]

x, y – center of gravity coordinates

n – number of measured samples

Parameter "Area" (cm²/s) indicates the area, which describes variation of center of gravity during the examination (2).

$$N_i = \frac{\left|(y_{i+1} - y_0) * (x_i - x_o) - (y_i - y_o) * (x_{i+1} - x_0)\right|}{2} \quad (2)$$

$$A = \frac{1}{t}\sum_{i=1}^{n-1} N_i \ \ [\text{mm}^2/\text{c}],$$

where:

N_i – particular element of area calculation

t – length of measure [s]

x_0, y_0 – average values of center of gravity coordinate (3)

$$x_0 = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad y_0 = \frac{1}{n}\sum_{i=1}^{n} y_i \quad (3)$$

Parameter "Lat" (cm/s) expressing the resultant vector of the amplitude of the lateral center of gravity (the length of the lateral displacement of center of gravity during the measurement).

$$sum = \sum_{i=1} (x_i - x_{i-1}),$$
$$Lat = sum / t \quad (4)$$

where:

t – length of measure [ms]

x – center of gravity coordinates

Parameter "Ant-Post" (cm/s) is the anteroposterior amplitude gravity vector (length of anteroposterior displacement of center of gravity during the period of measurement).

$$sum = \sum_{i=1} (y_i - y_{i-1}),$$
$$Ant - Post = sum / t \quad (5)$$

where:

t – length of measure [ms]

y – center of gravity coordinates

Parameter "AP/Lat" is the ratio of anterior-posterior and lateral components of the examined balance, which reflects the overall dominance of directional amplitude gravity investigated.

$$\frac{AP_{closed}}{Lat_{closed}} = \frac{Ant - Post}{Lat}$$
$$\frac{AP_{open}}{Lat_{open}} = \frac{Ant - Post}{Lat} \quad (6)$$

Parameter "Romb Way" is the ratio of way with open and closed eyes. Express the ratio of a visual control of posture to maintain postural balance.

$$Romberg\ Way = \frac{Way_{closed}}{Way_{opened}} \quad (7)$$

Parameter "Romb Area" is the ratio of area with open and closed eyes.

$$Romberg\ Area = \frac{Area_{closed}}{Area_{opened}} \quad (8)$$

Statistical processing included testing the hypothesis that the sampling distribution was normal (Gaussian) distribution using the Kolmogorov-Smirnov and Shapiro-Wilk criteria. The null hypothesis of the absence of differences between samples in multiple comparison was tested using the non-parametric Kruskal-Wallis test with correction depending on degrees of freedom. Spearman's correlation coefficient was used to determine the relationship between individual indicators.

The differences between the samples were considered statistically significant at the significance level p (probability of erroneously rejecting the null hypothesis) less than 0.05. Data analysis was performed using MedCalc (MedCalc Software Ltd, Ostend, Belgium).

Results and Discussion

The obtained results of our measurements are shown in Table 1.

Table 1

Postural balance indicators in children with normal hearing

	Mean (± SD)		Median (75 % CI)	
	Eyes open	Eyes closed	Eyes open	Eyes closed
Way, cm/s	1.40 ± 0.54	2.01 ± 0.83	1.28 (1.08- 1.59)	1.88 (1.45-2.49) *
Area, cm/s²	0.29 ± 0.25	0.50 ± 0.41	0.27 (0.14-0.34)	0 , 43 (0.20-0.57) *
AP, cm/s	0.95 ± 0.41	1.44 ± 0.62	0.84 (0.73-1.15)	1.23 (1.03 -1.66) *
Lat, cm/s	0.83 ± 0.29	1.11 ± 0.47	0.75 (0.62-1.00)	1.05 (0.77-1.44) *
AP/Lat	1.15 ± 0.20	1.33 ± 0.27	1.15 (0.99-1.23)	1.33 (1.13-1.54) *

Notes: * - the difference between Open and Closed groups is statistically significant; SD - standard deviation; CI - Confidence Interval

Table 2

Romberg Way and Romberg Area Parameter Calculation Results

	Mean (± SD)	Median (75% CI)
Romberg Way	0.75 ± 0.23	0.75 (0.56-0.84)
Romberg Area	0.72 ± 0.42	0.62 (0.46-0.88)

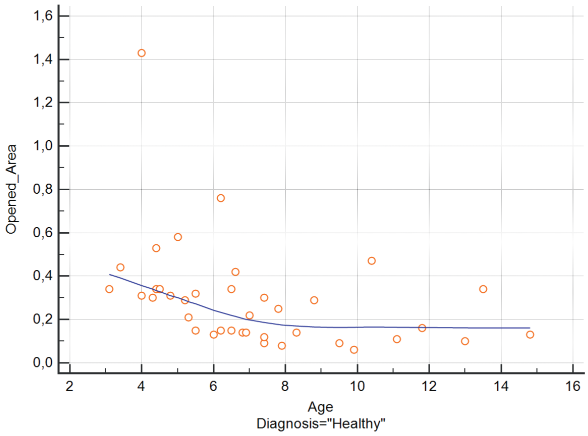
Notes: SD – standard deviation; CI – Confidence Interval

Obtained results were checked for conformity with normal distribution, no proper conformity was obtained. Therefore, all subsequent statistical processing of the results were performed using non-parametric statistics methods.

From Table 1 we can conclude that all postural balance parameters in children with normal hearing are statistically significantly increased in the closed-eyes position. Thus, the lack of visual control over maintaining posture leads to a statistically significant increase of all indicators, that describe a postural sway.

The next step was to analyze the individual indicators of the key Way and Area parameters, as well as to analyze the relationship between postural balance and age of the patients examined using the Spearman correlation coefficient.

A correlation was found between postural balance and patients' age (Fig. 3, Fig. 4). We have noted a trend towards a significant decrease in values until the age of 8. In the future, with age, balance indicators stabilized or slightly decreased.



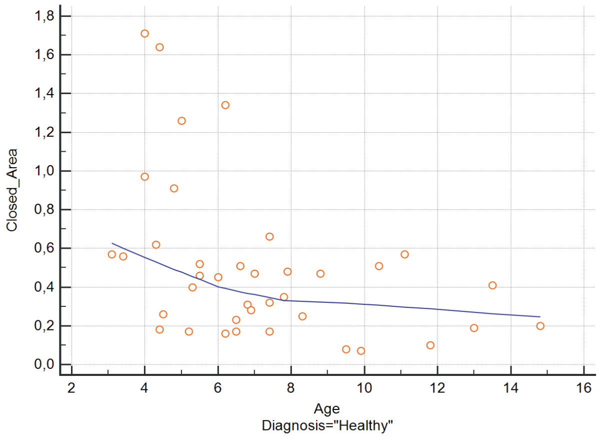


Fig. 3. Results of correlation analysis of the Area indicator depending on the patients' age.

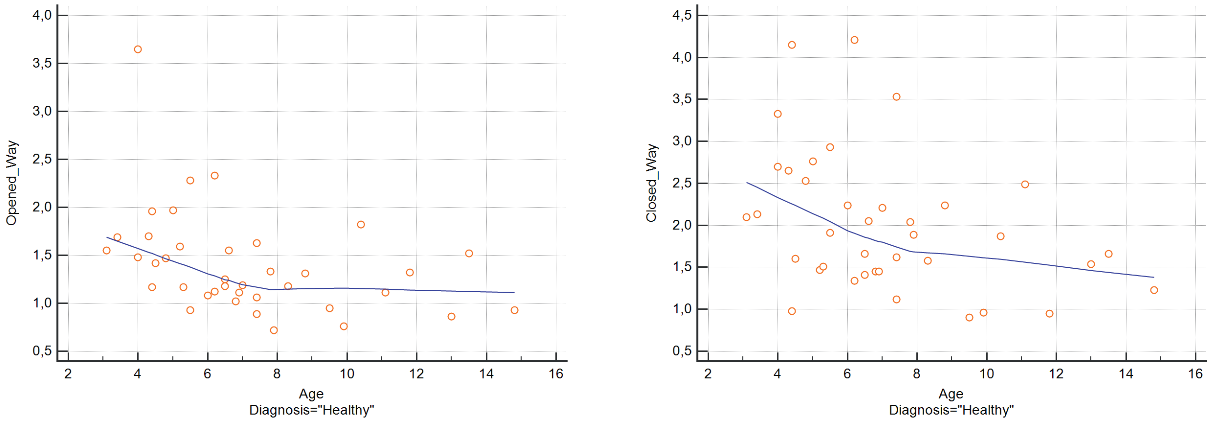


Fig. 4. Results of the correlation analysis of the Way indicator depending on the patients' age

Based on the graphical representation of the Way and Area indicators in open and closed eyes and based on the literature data [10, 11], we hypothesized that difference in postural balance indices exists in children of different ages. We divided the population of normally hearing children by age into two groups: group 1 - up to 8 full years (28 patients, ages 3.1 to 7.9 years), and group 2 – children over 8 years (10 patients, age 8.3 to 14.8 years). The results are shown in Table 3.

Table 3

Postural balance indicators in different age groups

	Group 1 Median (95% CI)		Group 2 Median (95% CI)	
	Eyes open	Eyes closed	Eyes open	Eyes Closed
Way, cm/s	1.38 (1.12-1.66)	2.05 (1.49-2.68)	1.15 (0.93-1.32)	1.56 (0.96-1.87)*
Area, cm/s2	0.30 (0.15-0.34)	0.47 (0.27- 0.64)	0.13 (0.10-0.29)*	0.23 (0.10-0.47)*
AP, cm/s	0.91 (0.78-1.17)	1.56 (1.09-1.87)	0.75 (0.64-0.92)	1.03 (0.71-1.22)*
Lat, cm/s	0.83 (0.66-1.02)	1.05 (0.8-1.52)	0.71 (0.54-0.78)	0.77 (0.55-1.25)
AP/Lat	1.15 (0.95-1.) 29)	1.35 (1.16-1.54)	1.16 (1.03-1.23)	1.27 (0.98-1.54)

Note. * - the difference between indicators in group 1 and 2 is statistically significant (P<0.05)

Table 4

Romberg Way and Romberg Area parameters in children of different age groups

	Group 1	Group 2
Romberg Way	0.75 (0.55-0.82)	0.78 (0.58-0.97)
Romberg Area	0.59 (0.40-0.86)	0.74 (0.56-0.92)

Note: statistically significant difference between groups1 and 2 was not obtained

We analyzed the parameter Way, which is one of the key to assess the balance and characterizes the speed of movement of the center of gravity. The median of this parameter in healthy children under the age of 8 years was 1.38 cm/s with the eyes open (Opened Way) and 2.05 cm/s with the eyes closed (Closed Way). In children older than 8 years, Opened Way was 1.15 cm/s and Closed Way was 1.56 cm/s.

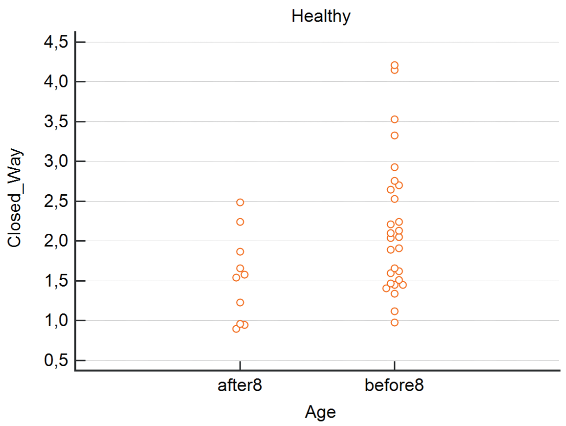


Figure 5. Distribution of Way Closed parameter values in children of different age groups

Comparing these indicators in children of all ages, we found a significant difference in the Closed Way scores in children of different age groups (p=0.036728), in children older than 8 years this indicator was significantly smaller. At the same time, no significant difference (p = 0.100723) was obtained in the Opened Way indicators (Fig. 5).

The next step was the Romberg Way coefficient analysis. This parameter shows the effect of vision on the velocity of the center of gravity displacement. The median of this parameter in healthy children under 8 years was 0.75, while in children older than 8 years, this figure was 0.78. We did not obtain a statistically significant difference between the indicators in these age groups (p=0.327851).

Further we studied the second important postural balance parameter, Area. The median of this parameter in healthy children under the age of 8 years was 0.30 cm²/s in the state with eyes open (Opened Area) and 0.47 cm2/s in the condition with eyes closed (Closed Area). In children older than 8 years, the Opened Area was 0.13 cm²/s and the Closed Area was 0.23 cm²/s.

We compared these indices for children of all ages, finding a statistically significant difference in both the Opened Area indices in both groups (p=0.044517) and the Closed Area indices (p=0.041402). In children older than 8 years, both indicators were significantly lower.

Derived from the Area parameter is the Romberg Area parameter, which characterizes the effect of visual control on the area of oscillation of the center of gravity. The median of this parameter in healthy children under 8 years was 0.56, and in children older than 8 years, this figure was 0.74. We did not obtain a statistically significant difference between the indicators in different age groups (p=0.288654).

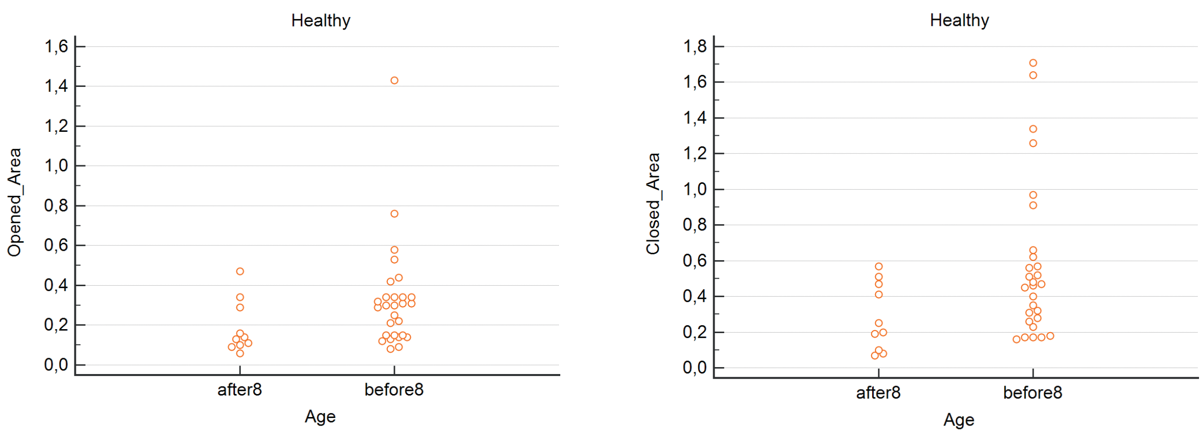


Figure 6. Distribution of Area parameter values in children of different age groups.

The Lat parameter, which describes the length of the lateral displacements of the center of gravity during the study, we investigated as follows. The median of this parameter in healthy children under 8 years was 0.83 cm/s in the open-eyed condition and 1.05 cm/s in the closed-eye condition (Closed Lat). In children older than 8, Opened Lat was 0.71 cm/s and Closed Lat was 0.77 cm/s. When comparing these indicators in children of different ages, we did not find a significant difference, both in Closed Lat indices in children of different age groups (p=0.144459) and in Opened Lat indices (p=0.144569).

The AP parameter is the length of the anterior-posterior displacements of the center of gravity during the study. The median of this parameter in healthy children under 8 years of age was 0.91 cm/s in the open-eye state (Opened AP) and 1.56 cm/s in the closed-eye condition (Closed AP). In children older than 8 years, Opened AP was 0.75 cm/s and Closed AP was 1.03 cm/s.

Closed AP index differed significantly in children of different age groups (p=0.012896), and in children older than 8 years this indicator was significantly lower. No significant difference was found in Opened AP index (p=0.056461).

The AP/Lat parameter represents the ratio of the anterior-posterior and lateral components of the study balance. The median of this parameter in healthy children under the age of 8 years was 1.15 in the Opened AP/Lat condition and 1.35 in the Closed AP/Lat condition. In children older than 8 years, Opened AP/Lat was 1.16 and Closed AP/Lat was 1.27.

Opened AP/Lat index did not differ significantly between two groups (p=0.907543) and no significant difference in Closed AP/Lat (p=0.327957) was obtained.

The WBB platform, with excellent convergence validity compared to laboratory-grade force platforms, has the following advantages: much lower cost, light-weight, no wired connection to the computer, can be easily used in outpatient clinical practice to assess postural balance in children.

Comparison with results of other studies

We did not find any studies evaluating the postural balance in children under 8 using the WBB, so compared the results with studies where the main parameter was COP velocity (Way parameter in our work). In Shams' paper, the postural balance was studied using the EquiTest platform, this parameter was 3.82 ±0.28 and 4.30 ±0.23 cm/s with eyes open and with eyes closed respectively in children aged 4-6 years, decreasing to 3.16 ±0.85 and 3.52 ± 0.68 at the age of 6-8 years, and to 3.29 ±0.71 and 3.58 ±0.62 at the age of 6-8 years. In our study, the median of the Way parameter in children under 8 years old was 1.38 and 2.02 cm/s in the position with open/closed eyes. These significant differences are present likely due to differences in hardware and software used.

Kelly et al. assessed postural balance in children after cochlear implantation and healthy controls [15]. COP was outcome variable, but no units of measurement available in the article. So it is impossible to assess consistency of both studies.

Pérez-Alenda et al. used four balance parameters in healthy children and children with haemophilia: standard deviation of anterior–posterior (SDAAP) and medial–lateral (SDAML) amplitude, as well as standard deviation of anterior–posterior (SDVAP) and medial–lateral (SDVML) velocity [16]. SDAAP and SDAML indeces represent standart deviation of CoP displacements relative to the mean of displacements, while SDVAP and SDVML indexes represent the average speed of CoP displacements relative to the mean velocity. Due to different mathematical origin of data is impossible to compare these parameters with results of our study.

Larsen et al. used mean COP length and mean COP velocity as outcome variable in their study of healthy children aged 10-14 years [17]. Mean COP velocity was 1.99±0.4 cm/s in open eyes and 2.76±0.6 cm/s in closed eyes test, which is far more than results in children older than 8 years in our work. It could be explained by different software used in our studies.

Thus, normative postural balance indicators in children obtained by using the WBB platform and Posturografie software can be used for further research with some limitations:

- difficulty of consistency comparison with other authors results

- lack of posturography parameters standartization

- different protocols, outcome variables and software used in WBB assisted balance assessment.

Conclusions

We obtained quantitative data of postural balance in healthy children using the Wii Balance Board and Posturografie software. These results can be used for further research using the Wii Balance Board (WBB) platform.

Numerical indices of postural balance are significantly increased when recorded in a closed-eyes position in children of all ages.

Parameter Area, which describes center of pressure variation during the examination, registered with opened eyes, decreases significantly with increasing of children age.

The postural balance parameters of Way, Area, AP obtained with the closed-eye study are likely to decrease with increasing age.

The Wii Balance Board platform has valuable advantages over laboratory-grade force plates when used in busy clinical practice.

Postural balance assessment with WBB needs standartization of outcome variables for improving the results consistency comparison

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Declarations of interest: none

The authors declare no conflicts of interest.

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A b s t r a c t

Posturography provides valuable information about the balance. Wii Balance Board is inexpensive and when used with specially designed software is a potentially effective tool for instrumental balance assessment.

Objective: To study the main outcome variables of postural balance in healthy children using the Wii Balance Board platform.

Methods: Postural balance parameters of 38 children with normal hearing and without vestibular complaints were recorded using Wii Balance Board and Wii Posturografie software. Way, Area, Lat, Ant-Post, AP/Lat parameters in position with eyes opened and closed were measured. Romberg Way, Romberg Area parameters were calculated.

Results: Numerical values of postural balance in children significantly increased with closed eyes position. The parameter Area, obtained during the study in open eyes, was improving with increasing the children age. The parameters of postural balance Way, Area, AP, obtained during the study with eyes closed, were likely to be decreased with increasing age of a child.

Conclusion: This paper describes the quantitative data of postural balance in healthy children obtained with the Wii Balance Board platform and Wii Posturografie software.

Key words: Postural balance, Pediatrics, Posturography, Force platform, Wii.

ОЦІНКА ПОСТУРАЛЬНОГО БАЛАНСУ У ДІТЕЙ З НОРМАЛЬНИМ СЛУХОМ З ВИКОРИСТАННЯМ ПЛАТФОРМИ WII BALANCE BOARD

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А н о т а ц і я

Постурографія надає цінну інформацію про баланс. Платформа Wii Balance Board – недороге обладнання і при використанні зі спеціально розробленим програмним забезпеченням є потенційно ефективним інструментом для інструментальної оцінки балансу.

Мета: вивчити основні складові постурального балансу у здорових дітей за допомогою платформи Wii Balance Board.

Методи: параметри постурального балансу у 38 дітей з нормальним слухом і без вестибулярних скарг були записані з використанням платформи Wii Balance Board і програмного забезпечення Wii Posturografie. Визначались параметри Way, Area, Lat, Ant-Post, AP/Lat в положенні з відкритими і закритими очима. Були розраховані параметри Romberg Way, Romberg Area.

Результати: Кількісні значення основних складових постурального балансу у дітей достовірно збільшувались при закритих очах. Параметр "Area", отриманий при дослідженні з відкритими очима, покращувався зі збільшенням віку дітей. Параметри постуральної рівноваги Way, Area, AP, отримані при дослідженні із закритими очима, ймовірно, будуть погіршуватись зі збільшенням віку дитини.

Висновок: Описано кількісні показники постурального балансу у здорових дітей, отримані за допомогою платформи Wii Balance Board і програмного забезпечення Wii Posturografie.

Ключові слова: постуральна рівновага, педіатрія, постурографія, Wii Balance Board.