

# Balance control of children and adolescents suffering from vertigo symptoms: in what way posturography is helpful in clinical evaluation of vestibular system pathology?

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*Purpose:* The aim of the study was to determine balance parameters in a group of young patients with vertigo symptoms and to verify posturography helpfulness in clinical evaluation of vestibular system pathology. *Methods:* 77 children and adolescents of age 3–18 suffering from vertigo episodes participated in the study (46 girls, 31 boys). They underwent audiology objective tests and balance test on stable surface. Calculated balance parameters were analyzed in reference to: eyes opened and closed, age influence, sway comparison in anterior-posterior and medial-lateral, differences between subgroups with and without vestibular deficits. Discriminant analysis was performed to assess classification ability to impaired group in two cases: only balance parameters and both audiology and balance parameters. *Results:* Patients with vertigo symptoms generally keep their balance properly on stable surface. Balance parameters do not depend on presence of vestibular system pathology. Values increased in eyes closed conditions. Left/Right and Anterior/Posterior differences were not statistically significant. The negative correlation between age and some balance parameters is present, stronger in the case of eyes opened and weaker or absent in vestibular impaired group. Also, correlations between axes were found, higher in impaired group in comparison with not impaired one. *Conclusions:* Discrimination based on balance parameters is poor not comparable to one built on combined: audiology and balance parameters, so typical balance parameters' analysis is not so useful in clinical practice when the reason of vertigo episodes should be assessed, but verify compensation process and measure with objective numbers the progress of recovering, the actual functional patient's status.

*Key words:* children, vertigo, balance, stable surface

## 1. Introduction

Balance control is very demanding task, develops from date of birth to adulthood and is dependent on sensory inputs: visual, vestibular and somatosensory. Assaiante [1] pointed out that development of balance strategies needs to overcome multiple interactions between the two functional principles: reference frames (head stabilization and pelvis stabilization) and body

joints linkage ("en bloc" and articulated) during different posture-kinetic tasks. The author confirmed that the age of 6–7 is very important when strategy changes from "en bloc" of head-trunk unit with dominance of visual inputs to articulated with dominance of vestibular inputs. In final maturation process of balance control the sufficient usage of somatosensory inputs appear with full coordination of all sensory information. Additionally, Assaiante emphasized the rule of pelvis stabilization during locomotion in all age groups in-

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cluding pre-walkers, what prompted the author to treat pelvis as the reference frame in most posture-kinetic activities.

Vertigo is defined as sensation of rotational environment motion and together with dizziness is common problem in elderly population. It affects about 15–20% of adults yearly [11]. According to this publication, vertigo and dizziness is caused by vestibular vertigo in 25% of cases, additionally a 12-month prevalence is estimated at 5% and an annual incidence at 1.4%. Additionally, the problem rises with age and is three times more frequent in women than in men. As the most common reasons of vertigo the author mentioned: benign paroxysmal positional vertigo (BPPV), vestibular migraine (VM), Menière's disease (MD). Neuhauser [2] emphasized that BPPV and VM are underdiagnosed, while MD is overdiagnosed in spite of the fact that it is 10 times less frequent than BPPV. Also consistent association of vertigo and migraine is based in literature.

Vertigo symptoms are also registered in children and adolescents and their prevalence is estimated at 0.7% to 15%, with higher values obtained on questionnaire-based diagnosis [5]. This review article, based on 9 studies and 724 total patients, pointed as the predominant causes of vertigo in children: VM 28%, benign paroxysmal positional vertigo of childhood (BPVC) 16%, vestibular neuritis 10%, psychogenic vertigo 8%, Meniere's disease 4%, otitis media (OM)/middle ear effusion (MEE) 4%, head trauma 4%, BPPV 2% and orthostatic hypotension 0.6%. Causes of vertigo in childhood change with age: pre-school age group mostly suffer from BPVC, children of school age from BPVC and VM, and adolescents from VM [9].

The problem is very important because concerns patient and his/her parents. Russell G. et al. [15] stated that only 48% of vertigo episodes are explained by parents in conjunction with infection, trauma or migraine. This fact multiplies the anxiety, especially that children can have problems with naming phenomena they suffer from and parents do not exactly know what their children experience. Both adults and children with vertigo episodes can finally suffer from psychological vertigo-related handicap with imbalance problems [13], [14]. These problems could increase the fall risk.

Different tools are used for clinical and objective diagnostics for assessing reasons of vertigo: ENG (electronystagmography), rotatory chair test, Dix–Hallpike test, PTA (pure tone audiometry), ABR (auditory brainstem responses), CT (computed tomography), MRI (magnetic resonance imaging), Angiography [4]. Klaus [10] noticed that, in spite of the fact that vertigo and

imbalance can be diagnosed based on history and clinical tests, it can be observed with the use of new technologies, such as recording eye and head movements with high resolution video-oculography (256 Hz) and inertial sensors, posturographic measures and quantitative gait analysis, which further helps to distinguish balance disorders.

The problem of balance in vertigo in children population was described on a wide age group of Finland's population as questionnaire-based research [12]. But according to research of Chiarovano et al. [3] there is no correlation between subjective self-report test (in case of that study it was Dizziness Handicap Inventory DHI) and measures of balance while visual inputs are perturbed with Virtual Reality (VR). Generally, the literature describing the balance parameters of posturography in children suffering from vertigo episodes is lacking.

The aim of the study was to determine the balance control of the group of patients with vertigo symptoms in childhood and adolescence and to verify in what way posturography can be helpful in clinical evaluation of vestibular system pathology.

## 2. Methods

In this retrospective study participated 77 children and adolescents aged 3–18 (median 12) treated in Audiology and Phoniatic Department of The Children's Memorial Health Institute in Warsaw, Poland, because of their vertigo episodes (46 girls and 31 boys). Typical objective and subjective hearing tests were performed in all examined patients to diagnose vestibular and inner ear status. PTA (pure tone audiometry), DPOAE (Distortion Products Otoacoustic Emissions), BEAP (Brainstem Evoked Auditory Potential), tympanometry with stapedial muscle reflexes and VEMP (Vestibular Evoked Myogenic Potential) were performed. Spontaneous nystagmus, gaze nystagmus, positional nystagmus, Dix–Hallpike test were assessed in Frenzel video-goggle. Smooth pursuit tracking, Saccades, Optokinetic Nystagmus, Caloric tests were done on ENG test. 41 patients (aged 3–18) had confirmed pathology connected with: BPPV 7 (17%), vestibular pathology (unilateral or bilateral weakness) 20 (49%), others – 14. Unilateral or bilateral weakness was represented by: left labyrinth weakness (12 patients), right labyrinth weakness (7), bilateral labyrinth weakness (1). Age of patients without vestibular problems was 4.5–17 years. Exclusion criteria were the comorbidities which could additionally influence

functional capacities of the patients. Additionally, they also underwent objective balance test, performed using Kistler piezoelectric platforms combined with optoelectronic movement system Vicon. Sampling frequency was 1000 Hz, finally decimated into 60 Hz – the frequency the laboratory norm was captured.  $X$ ,  $Y$  coordinates of Centre Of Pressure (COP) from a 30-second test on stable surface with eyes opened (EO) and closed (EC) were captured. Test position was: legs pelvis-wide, arms along the body, general position self-preferred.

Balance parameters calculated in Matlab:

- 1) maximal radius ( $R_{\max}$ ) – maximal sway occurred during test with no direction indication [mm],
- 2) average radius ( $Ra$ ) – average sway occurred in the test with no direction indication [mm],
- 3) maximum anterior, posterior, left and right sway (MaxA, MaxP, MaxL, MaxR) – maximal sway in the test in specified direction respectively anterior, posterior, left and right [mm],
- 4) sway path length (PathLength) – total sway length occurred during test [mm].

Patient's data were compared to laboratory norm (except maximal radius) and the number of the abnormal parameters was calculated for both EO and EC conditions. According to audiology test's results, patients were classified to group with or without problems with vestibular system. Balance parameters were summarized for the whole group and compared to norm. Also balance parameters were analyzed in reference to: EO and EC conditions, age influence, anterior-posterior and medial-lateral sway comparison, differences between subgroups – with and without vestibular deficits. Discriminant analysis was performed to assess classification ability to impaired group in two cases: only balance parameters and both audiological and balance parameters.

Laboratory norm was calculated from balance data captured with the same Kistler platform that was used

in this study, but under supervision of the first Vicon system (1990) which limited the capture frequency to 60 Hz. This forced the use of decimating procedure of data captured in this study. Normal group consisted of children and adolescents aged 6–18 without balance, neurological or orthopedic problems.  $Ra$ , MaxA, MaxP, MaxL, MaxR were calculated as minimal and maximal normal values. No statistically significant differences were found in relation to age or gender. Laboratory norm in EO and EC closed conditions are presented in Table 1 and are used in our everyday clinical practice.

Statistical calculations were performed in Statistica. The normality of distribution of all variables was checked with Shapiro–Wilk test. For frequency of occurrence analysis  $\chi^2$  Pearson test was used. Mann–Whitney  $U$ -test and Wilcoxon matched-pairs test were used for comparing results of independent and dependent variables respectively.  $R$ -Spearman test was applied for correlation calculations. Statistical significant level was  $p = 0.05$ .

### 3. Results

Due to non-parametric distribution of height, body mass and balance parameters, all were summarized as median. Median height was 155 cm (range of 97–190), median weight was 46.7 kg (range of 14.4–84). Balance parameters are presented in Table 1. Median values of all parameters for all 77 patients were within the labs norm. 30 patients had at least one parameter higher than norm in EO conditions and 31 in EC conditions respectively. In EO conditions 12 of them had confirmed vestibular pathology (18 without), in EC conditions 16 with and 15 without, respectively. There was not statistical significance difference in quantity of increased balance parameters results and vestibular

Table 1. Median, min and max values of balance parameters calculated from 77 subjects balance test with balance parameters of laboratory norm (Lab reference).  $R_{\max}$  maximal radius,  $Ra$  average radius, MaxL max left sway, MaxR max right sway, MaxA max anterior sway, MaxP max posterior sway, EO eyes opened, EC eyes closed

[mm]	$R_{\max}$ EO	$Ra$ EO	PathLength EO	MaxL EO	MaxR EO	MaxA EO	MaxP EO
Median value	16.7	6.2	382	9.0	9.3	12.7	12.6
Min value	5.4	2.2	61.7	3.8	2.6	4.4	3.4
Max value	45.1	18.9	1180	30.5	38.9	38.9	44.3
Lab reference		1.5–13.4	97–445	3–26	3–24	3–24	3–20
	$R_{\max}$ EC	$Ra$ EC	PathLength EC	MaxL EC	MaxR EC	MaxA EC	MaxP EC
Median value	19.0	6.7	533	11.6	11.7	14.7	15.2
Min value	9.1	2.8	244	3.3	1.8	6.5	5.4
Max value	86.9	36.6	2805	79.1	57.3	59.6	66.4
Lab reference		2.2–11.7	143–626	5–25	4–27	4–27	3–25

Table 2. Correlation between age and balance parameters for patients suffering vertigo symptoms overall and separately for subgroups with and without vestibular system pathology confirmed. NS – no statistically significant correlation

R Spearman	$R_{\max}$ EO	Ra EO	PathLength EO	MaxL EO	MaxR EO	MaxA EO	MaxP EO
Overall	-0.32	-0.36	-0.55	-0.33	-0.43	-0.31	-0.32
Vestibular system pathology	NS	NS	-0.45	NS	NS	-0.33	NS
No vestibular system pathology	-0.44	-0.55	-0.66	-0.50	-0.60	NS	-0.38
R Spearman	$R_{\max}$ EC	Ra EC	PathLength EC	MaxL EC	MaxR EC	MaxA EC	MaxP EC
Overall	NS	NS	-0.37	-0.31	-0.28	NS	NS
Vestibular system pathology	NS	NS	NS	NS	NS	NS	NS
No vestibular system pathology	NS	NS	-0.60	-0.60	-0.61	NS	NS

system pathology presence (EO:  $\text{CHI}^2$  Pearson 3.4644  $df = 1$   $p = 0.0627$ , EC:  $\text{CHI}^2$  Pearson 0.0556  $df = 1$   $p = 0.8135$ ).

Although patients experiencing vertigo have similar parameters regardless of whether vestibular system pathology has been confirmed or not, Mann–Whitney  $U$ -test gave the lowest value  $p = 0.0931$  in the case of path length, the highest  $p = 0.9430$  in  $R_{\max}$  EC, the difference between EO and EC conditions in pathology subgroup was revealed in all parameters ( $p < 0.05$ ), while only 3 appeared in the subgroup without pathology (PathLength, MaxL and MaxP sway). Values increased in case of EC conditions. Left/Right and Anterior/Posterior differences were not statistically significant (Wilcoxon matched-pairs,  $p > 0.05$ ), also taking the division with vestibular system status and without into account.

As a doubt can appear whether younger children included to this study performed balance test reliable, all parameters were also compared between patients aged 3–5 (only 8 patients) and above 6 years old. According to Mann–Whitney  $U$ -test's result, only path length in EO ( $p = 0.0034$ ) and EC ( $p = 0.0097$ ) are different in this division (younger patients: median EO 587, EC 733, older group: EO 370, EC 520 mm).

The correlations between age and some balance parameters were assessed, specified in Table 2. They were negative and generally stronger in the case of EO and much weaker or absent in group with vestibular system deficit diagnosed. Also, correlations between axes were found (Table 3). The highest correlation was between MaxR and MaxP in EC conditions and generally correlations were higher in impaired group, compared to the not impaired one.

Combining audiology and otoneurology results with balance data the attempt to assess whether analyzed balance parameter can help clinician to confirm

vestibular system pathology, discriminant analysis was performed.

From balance parameters, maximal radius of sway EC ( $R_{\max}$  EC) and maximal right sway EC (MaxR EC) turned out to be discriminating variables (respectively, Wilks' Lambda 0.999741 and 0.990270,  $p = 0.064029$  and 0.098470). Both  $p$  values are greater than typically assumed  $p = 0.05$ . Classification equations are:

$$\text{Yes} = -2.15069 + 0.15228 R_{\max\_EC} - 0.04249 \text{MaxR\_EC}$$

$$\text{No} = -1.94381 + 0.09223 R_{\max\_EC} + 0.02640 \text{MaxR\_EC}$$

Classification matrix is presented in Table 4.

Table 3. Significant correlation between Left (L)/Right (R) and Anterior (A)/Posterior (P),  $p < 0,05$  in all group of the study and in group with confirmed vestibular system deficit

Overall vertigo	MaxA EO	MaxP EO	MaxA EC	MaxP EC
MaxL EO	0.49	0.51		
MaxR EO	0.55	0.56		
MaxL EC			0.48	0.55
MaxR EC			0.48	0.59
Vestibular system impaired	MaxA EO	MaxP EO	MaxA EC	MaxP EC
MaxL EO	0.59	0.64		
MaxR EO	0.58	0.58		
MaxL EC			0.53	0.63
MaxR EC			0.57	0.65

When balance and audiological parameters were combined, caloric preponderance and maximal posterior sway EC (MaxP EC) are discriminating variables (respectively, Wilks' Lambda 0.958258 and 0.949458,  $p = 0.044514$  and 0.060454), although MaxP EC has

$p$  values greater than 0.05. Classification equations are:

$$\text{Yes} = -5.5473 + 3.6144 \text{ Caloric preponderance} + 0.22253 \text{ MaxP\_EC}$$

$$\text{No} = -3.8454 + 2.84403 \text{ Caloric preponderance} + 0.17171 \text{ MaxP\_EC}$$

Classification matrix is presented in Table 4.

Table 4. Classification matrix of discriminant analysis of patients with vertigo symptoms to vestibular system deficit's group regarding only balance parameters and combined: balance and audiology parameters

Only balance parameters	Percentage – Correct	Yes – $p = 0.533$	No – $p = 0.468$
Yes	58.5	24	17
No	50.0	18	18
Together	54.6	42	35
Combined balance and audiology parameters	Percentage – Correct	Yes – $p = 0.559$	No – $p = 0.441$
Yes	63.6	21	12
No	73.1	7	19
Together	67.8	28	31

## 4. Discussion

Patients with vertigo symptoms generally keep their balance properly when standing on stable surface. Generally, balance parameters decrease with age, what is also registered in healthy population [18]. Our lab norm is not dependent on age, what is the limitation of this study, because some adolescents could be regarded as normal, while in more narrowed reference data they would be designated as having increased sway. Another question can appear why the lab norm valid for healthy subject aged 6–18 years was used for younger vertigo subjects, especially that repetition of balance indices of children under 6 years old is poor [16], [17]. Only 8 subjects aged 3–5 were able to fulfill criteria of quiet standing to regard their results as reliable. On the other hand 5 of them finally had confirmed vestibular system deficit (i.e., 12% of all subject with pathology). Additionally only path length of younger subjects differ from older ones, and according to results of correlation between balance parameters and age in group with vestibular deficit (Table 2) only path length and maximal anterior sway in eyes opened conditions (medium or weak) was significant and no significant correlations were found in eyes

closed conditions. So younger subjects differ from older ones not in the meaning of increased instability (fall risk) but only of increased correction movements they perform to keep stability position. Also regarding Assaiante's conclusions [1] and the fact that children differ in maintaining balance keeping strategies don't imply that 'en bloc' strategy (applied by younger children) is always less sufficient. Those arguments are in favor to include 3–5 years old subjects into analyses. Fact that balance parameters of vestibular impaired patients are more weakly dependent on age in comparison to not impaired ones, and generally in EC conditions the difference between ages decreases suggests that patients when conscious of their problems, try to focus more on more difficult tasks of keeping balance.

The study was performed on a group of patients with no movement impairments and correct muscle strength which could help them to keep correct stability [6].

According to Jasper et al. [8] review paper, posturography has limited application in clinical practice. Max posterior sway is the only balance parameter that can suggest vestibular system pathology in conjunction with caloric preponderance. Discriminant analysis based on balance parameters used in that study is poor (approx. 50%), not comparable to one built on combined: audiological and balance parameters (almost 70%), so typical balance parameters' analysis is not so useful in clinical practice when the reason of vertigo episodes should be assessed, but verify compensation process and measure with objective numbers the progress of recovering, the actual functional patient's status. Our study's results suggest that compensation mechanism appear quickly and is sufficient in children and adolescents with proper muscles strength or at least satisfying enough, therefore basic static balance tests do not show discrepancies from normal ones.

However discriminant analysis in this study allows for some conclusions. Maximal right sway is classification variable to vestibular system pathology in model consisted of balance parameters. 29% of patients with confirmed pathology suffered from left labyrinth weakness, which could influence this calculation, but otherwise discriminant coefficient is four times smaller than maximal radius coefficient. In contrast to combined discriminant analysis, the results pointed to delicate dependence of maximal posterior sway, what can be dangerous for patients because base of stability is the lowest in this direction.

The literature suggests that advanced tests with head movement of higher cadence, combining even 3D moving kinematic and EMG signals with stochas-

tic perturbations of platforms could enable better assessment of these patients [8], but this requires equipment of advanced technology.

In our opinion, further research is necessary, also on unstable surface, e.g., leaned, foam [7] and using functional tests on that group of patients, because it is different from adult one (less influence of degenerative diseases) and require quick tests. Also some papers emphasize their usefulness in BPPV affected adult population [19]. According to Jasper et al. [8], reports are contradictory because of poor homogeneity of patients in analyzed studies, but the studies they regarded was based on older population [8]. Looking for sufficient, short lasting tests for children population researches based on group of patients with vertigo symptoms seems to be appropriate in this sense, because this group is homogenous in the meaning of concomitant diseases lack characteristic for older population.

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