Postural Control in Deaf Children

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Received: 25 May 2016; Accepted: 31 Dec. 2016

Abstract- This cross-sectional study aimed to determine the reliability of static control evaluation with Synapsys Posturography System (SPS, Marseille, France) and to compare the static postural control of deaf children with typically developing children. This study was conducted in 2 phases on 81 children of 7 to 12 years old in Tehran schools. The first phase examined the reliability of static balance evaluation with SPS. In this phase, a total of 12 children with typical development were evaluated and then do a re-test 1 week later. In the second phase, 30 children with profound sensorineural hearing loss (SNHL) and high risk in their balance (selected from Baghcheban Schools for the Deaf) as the experimental group, and 37 children with typical development (selected randomly from 2 primary schools for girls and boys in District 12 of Tehran Department of Education) as control group were enrolled in the study. They were all placed under sensory organization test evaluation. Based on the results of intraclass correlation coefficient (ICC), the unilateral random effects model, test-retest reliability in different sensory conditions, the moderate to excellent results were obtained (ICC between 0.68 and 0.94). Also, the mean displacement of pressure center in all sensory conditions, the limits of stability (LOS) area, the overall balance scores, and scores for balance sensory ratio (except the somatosensory ratio) of children with typical development were better than the deaf peers ($P<0.05$). The SPS has acceptable reliability to evaluate static posture in children between the ages of 7 and 12 years. Furthermore, deaf children as compared to children with typical development had a lower static postural control in all sensory conditions. This finding confirms the need to examine the postural control for identifying the extent of sensory deficit that has caused poor balance function, and also the need for early intervention to address the balance deficit in deaf children.

Acta Med Iran 2017;55(2):115-122.

Keywords: Postural control; Balance; Deaf children; Sensory organization test

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Introduction

Postural control or balance is an essential prerequisite of most daily activities in children (1). The purpose of postural control is to ensure the optimum condition of body center relative to the surface on which the child stands in upright stance, to achieve sufficient stability under different conditions (2). Postural control is essential for the development of motor skills (3). Besides its vigorousness and flexibility, it must effectively discover and integrates the vestibular, visual, and proprioceptive inputs (2).

Because of the close relationship of cochlear and vestibular systems, loss of vestibular function strongly affects postural stability (4). Development and maintenance of posture is a multi-component process that is not unique to vestibular input. Changes in the maturation of other sensory systems (mainly visual and somatosensory), central nervous system processing, and coordination of motor output are responsible for posture skills throughout adolescence period (5).

Because postural control is a key predictor of children's motor development, the presence of a valid evaluation to identify postural stability weakness is necessary for therapists who work with children. Deaf children compared with typically developing peers are at greater risk of balance deficit and loss of gross motor skills (1). Regarding the necessity of balance in children,

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to understand better the functions of sensory mechanisms in maintaining postural control in deaf children, we need further studies. There are several tests available to assess postural stability organization. Among these tests, sensory organization posturography is increasingly used in clinical settings (1).

Sensory organization test (SOT) is the standard test for measuring the assistance and interaction of the visual, somatosensory, and vestibular systems during the postural response to 6 changes in sensory conditions. This test is conducted through measuring postural sway. It has been designed to quantify a person’s ability in using different sensory systems for maintaining balance in standing position (6). Although posturography neither directly measure the peripheral and central vestibular function (7) nor provide any information regarding the location of a lesion or the degree of impairement (8), it is still a useful tool for identifying impairments associated with dysfunction of the vestibular-spinal system (7) and assesses the balance under different simulated sensory conditions. Therefore, under the more functional conditions (8) and sensory ratios calculated from the achieved results, it can be used to monitor the predominance or effectiveness of sensory system maturation in postural control (9).

The child’s age and equipment used affect the posture’s degree of sway and reliability of measurements (10). Considering that the sensory organization of children with Synapsys Posturography System (SPS) (Synapsys, Marseille, France) was not available in Iran, this study aimed to determine the reliability of SPS in assessing static postural control in addition to determine the postural control sensory organization in deaf children between the ages of 7 and 12 years. The obtained results will be useful not only to evaluate but also to plan early intervention and assess its progress in deaf children suffering from imbalance.

Materials and Methods

This cross-sectional and analytic study was conducted in 2 stages on 81 children between the age of 7 and 12 years, consisting of 25 girls and 46 boys. The first stage was to examine the reliability of static balance evaluation with SPS. A total of 12 children (5 girls and 7 boys) with typical development were evaluated and then do a re-test 1 week later.

In the second stage, we compared the postural control of deaf children to typically develping peers in anteroposterior (AP) and mediolateral (ML) positions. A total of 37 children with typical development (10 girls and 27 boys) and 30 children (20 boys and 10 girls) with the profound sensorineural hearing loss (PTA≥90 dB) with high risk in balance were assessed through sensory organization test with SPS (Synapsys, Marseille, France). Out of deaf children, 20 had unilateral cochlear implant, and the overall score of their BOTMP (The Bruininks-Oseretsky test of motor proficiency)’s balance subtest was 2 standard deviations lower than children with the normal hearing of the same age (11).

The hearing level of the children was measured by audiometry. Children who, in addition to hearing loss, suffered from visual, physical, neurological, and cognitive impairment were excluded from the study. This was confirmed by review of educational and medical records. Deaf children were selected from Baghchehban Schools for the deaf in Tehran City. As the SOT in children has not been normed in Iran, we used a group of typical development aged-matched children as a control group. Children with typical development was randomly selected from 2 primary schools for girls and boys in district 12 of the Department of Education of Tehran City. Prior to the test, its conditions were described in a written form to children’s parents whose written consents for letting their children’s participation in the study were obtained.

In the SOT, the child calmly stands on a static platform and is tested in 6 static conditions with different visual and somatosensory inputs. In the 3 initial conditions, the child stands on a firm surface. In condition 1, eyes are open, but in condition 2 the eyes are closed. In condition 3, the visual scene moves. The moving visual scene (cob web) is produced by a visual projection system in an otherwise completely darkened room. Condition 3 presents a situation of visual conflict, where visually accurate information is provided that is of no significant help in maintaining quiet stance. Condition 3 provides misleading visual visual cues about the position of the body in space. In conditions 4, 5, and 6, the somatosensory and proprioceptive information is not absent but becomes limited for standing in an upright stance by using compliant (foam) surface.

The test was performed in a room without distracting factors and during the evaluation, each child was asked to stand barefoot and as much as possible without motion while his or her hands were placed next to his or her body. At the beginning of evaluation, the first author of the article placed the child’s foot with a distance of 30° from one another. In the condition with open eyes, the child should directly look forward to the visual target that was placed 2.5 meters from him or her on the surface level. In the condition with closed eyes, to ensure of no visual feedback, the blindfold was used, and children were asked to stabilize their position as much as possible in the condition that they have already memorized the target. Duration of each condition was 20 seconds. Tow trials were conducted for each condition. The limits of stability (LOS) test was evaluated in the open eyes condition while the platform was fixed. The children were asked that while they were keeping their body in the upright stance, without taking a step, to sway in all directions as much as possible. The children were trained that without moving their arms or bending their torso, move their bodies like a piece of wood and use only the ankle strategy for carrying out their motions and not to raise their heels. Otherwise, the trial would be repeated.

Considering the learning process in sequential execution limits of stability, prior to recording the data for all children, a practice trial was carried out, and the duration of LOS execution was considered for 45 seconds. In deaf children, the manner to execute different stages of the test was explained by the first author through total communication so that it would be ensured that the children have understood the correct manner of carrying out the test.

The test-retest reliability (inter-sessions) of different sensory conditions of the SPS was analyzed by using the intraclass correlation coefficient (ICC) of the random unilateral model. For every ICC obtained, to prepare a range of values which was likely to cover the true population value, the confidence interval was considered as 95%. The ICC values were interpreted according to Fleiss general guidelines. Thus ICC>0.75 was labeled with excellent reliability, ICC between 0.4 and 0.75 with fair to good reliability, and ICC<0.4 with weak reliability (12).

In this study, the evaluation of posturography included the assessment of all conditions (Conditions 1-6), calculation of the scores for overall balance, values of sensory ratios, and the limits of stability area. Condition 1 evaluates balance with data from all 3 sensory systems. In condition 2, visual input is absent. In condition 3, the visual input and in condition 4, the somatosensory input are inaccurate. In condition 5, the visual input is absent and somatosensory input is inaccurate. In condition 6, the visual and somatosensory input is both inaccurate. The overall score shows the general level of sensory organization function and includes the mean weight of 6 sensory conditions with more emphasis on conditions 3 to 6.

Furthermore, since quantifying the relative difference of scores between 2 conditions leads to better identification of the particular nature of the child's difficulty in sensory balance, the relative difference between the scores is quantified by using the ratio. The somatosensory ratio compares condition 2 with condition 1 and measures the posture's stability when vision is absent. Therefore, it shows the ability of the child in using somatosensory input. The visual ratio compares condition 1 to condition 4 and measures the ability of the visual system function when the somatosensory input becomes limited. Next, the vestibular ratio compares condition 5 with condition 1 and measures the child's ability when both somatosensory and visual inputs are in turn limited or absent. Eventually, the vision preference compares conditions 3 and 6 with conditions 2 and 5 and measures the degree in which the child relies on visual information even when they are misleading. To examine whether the data are normal, the Kolmogorov-Smirnov test and for analyzing the static balance data, the Independent *t*-test was used. The significance level was set at $P<0.05$.

Results

The mean chronological age of children with typical development in the first phase of our study was 9.56±1.08 and in the second phase was 9.89±1.64, and the mean age of deaf children was 10.06±1.61 years (Table 1).

Table 1. Characteristics of each group

Group	n	Mean (SD), y	Gender	
			Male	Female
1	12	9.56(1.08)	7	5
2	37	9.89(1.64)	27	10
3	30	10.06(1.61)	20	10

1: Typically developing children in the first phase, 2: Typically developing children in the second phase, 3: Deaf children

The ICC results and 95% confidence interval reliability of the test-retest (inter-sessions) for 6 sensory conditions were obtained and are shown in Table 2.

Table 2. ICC and %95 confidence interval reliability of the test-retest for sensory conditions in children with typical developement

Condition	Mean measures ICC	%95 confidence interval
AP Con 1	0.68	0.00-0.90
ML Con 1	0.77	0.25-0.93
AP Con 2	0.72	0.12-0.91
ML Con 2	0.78	0.29-0.93
AP Con 3	0.78	0.31-0.93
ML Con 3	0.88	0.62-0.96
AP Con 4	0.78	0.27-0.93
ML Con 4	0.88	0.60-0.96
AP Con 5	0.74	0.15-0.92
ML Con 5	0.80	0.36-0.94
AP Con 6	0.75	0.16-0.92
ML Con 6	0.94	0.80-0.98

Abbreviations: AP, Anteroposterior; ML, Mediolateral; Con, Condition

The mean score for overall balance of postural stability in the anteroposterior (AP) and mediolateral (ML) directions of children with typical development and deaf children were, respectively 69.28(8.18), 75.16(9.47), 43.56(7.91), and 50.52(10.83), which had significant difference with each other ($P<0.05$) (Figure 1). Also, the mean numbers of the LOS area for children with typical development and for deaf children were, respectively 142.08±60.83 cm^2 and 103.63±32.71 cm^2, which had significant difference with each other ($P<0.05$) (Figure 2). The mean displacement of pressure center of all conditions of sensory organization test and also the scores for sensory balance ratio except the somatosensory ratio for deaf children were less than children with typical development ($P<0.05$). In Tables 3 and 4, respectively, the mean numbers and standard deviations of pressure center displacement for conditions of sensory organization test, LOS area, and sensory balance ratios and overall scores for deaf children and typically developing peers are shown.

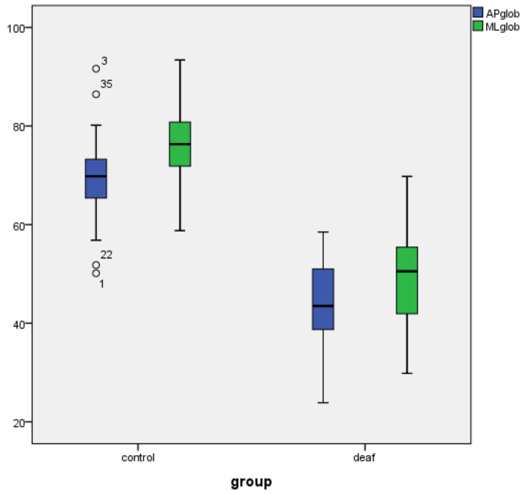

Figure 1. Box-plot of overall balance score of the 2 groups of children. Abbreviations: AP, Anteroposterior; ML, Mediolateral; Glob, Global

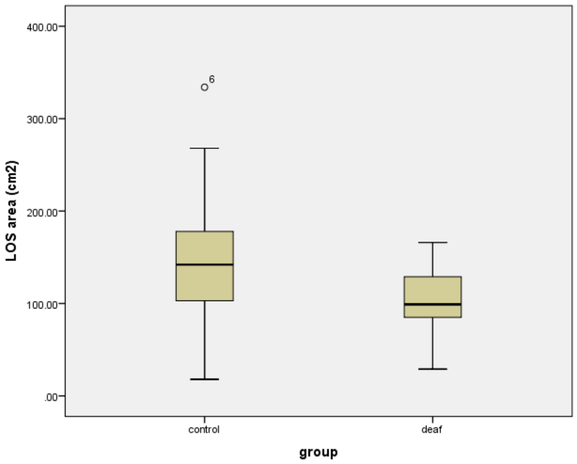

Figure 2. Box-plot of limits of stability (LOS) area of the 2 groups of children

Table 3. Comparision of posturography sensory conditions results between 2 groups of children

Condition	Group	n	Mean	SD	*P*
AP Con 1	1	37	85.37	5.50	<0.001
	2	30	75.14	10.66	
AP Con 2	1	37	81.39	7.09	<0.001
	2	30	72.49	10.85	
AP Con 3	1	37	67.30	12.19	<0.001
	2	30	52.72	16.62	
AP Con 4	1	37	78.01	8.98	<0.001
	2	30	56.26	15.45	
AP Con 5	1	37	65.68	9.71	<0.001
	2	30	21.36	17.53	
AP, Con 6	1	37	52.08	13.93	<0.001
	2	30	13.67	13.73	
ML Con 1	1	37	88.94	5.60	<0.001
	2	30	81.37	7.39	
ML, Con 2	1	37	86.76	5.60	<0.001
	2	30	79.48	7.39	
ML Con 3	1	37	73.24	14.53	0.003
	2	30	63.97	13.06	
ML Con 4	1	37	81.85	6.53	<0.001
	2	30	62.03	16.36	
ML Con 5	1	37	72.03	10.03	<0.001
	2	30	29.43	16.36	
ML Con 6	1	37	72.03	10.03	<0.001
	2	30	29.43	16.65	
LOS Area	1	37	142.08	60.83	0.003
	2	30	103.63	32.71	

Abbreviations: AP, Anteroposterior; ML, Mediolateral; LOS, Limits of stability; 1: children with typical development; 2: Deaf children

Table 4. Comparision of ratio of stability scores results between 2 groups of children

Ratio name	Group	n	Mean	SD	*P*
AP Som	1	37	0.95	0.05	0.44
		30	0.97	0.17	
ML Som	2	37	0.97	0.05	0.88
		30	0.97	0.08	
AP Vis	1	37	0.91	0.08	<0.001
		30	0.76	0.24	
ML Vis	2	37	0.92	0.06	<0.001
		30	0.76	0.19	
AP Ves	1	37	0.76	0.09	<0.001
		30	0.27	0.23	
ML Ves	2	37	0.80	0.09	<0.001
		30	0.36	0.29	
AP Pref	1	37	0.80	0.13	<0.001
		30	0.70	0.18	
ML Pref	2	37	0.84	0.11	0.01
		30	0.75	0.18	
AP Glob	1	37	69.28	8.18	<0.001
		30	43.56	9.47	
ML Glob	2	37	75.16	7.99	<0.001
		30	50.52	10.83	

Abbreviations: AP, Anteroposterior; ML, Mediolateral; Som, Somesthetic; Ves, vestibular; Vis, Visual; Pref, preferential; Glob, Global; 1: children with typical development; 2: Deaf children

Discussion

The static balance evaluation reliability by using the SPS showed that the reliability of the system is moderate to excellent (ICC between 0.68 and 0.94). As with many biological measurements, postural stability has inherent variability affected by physical, biomechanical, mechanical, and psychosocial factors. As a result, many elements such as motivation, concentration, fatigue, emotional condition, test time, and communication with the tester affect the reproduction of posture results (13). In this regard, for minimizing the variability between measurements of test-retest during the 2 sessions, the arrangement and sequence of measurements, the tester, and environmental factors were kept the same. Therefore, the moderate reliability in this study can be attributed to the inherent variability of the children's balance function.

In the case of deaf children's static balance, a loss in balance was seen in all conditions and results showed that the static postural control of deaf children in all conditions was significantly poorer than children with normal hearing. This finding is consistent with the results of previous studies. A study on 90 children between the ages of 8 and 10 suffering from severe sensorineural hearing loss (SNHL) with different etiology showed that most of these children presented with impaired static balance e.g., balance during single-leg stand (6). Results of the study by Derlich and colleagues (2) on postural control of deaf children and normal hearing peers showed that there is significant difference between the postural control of these children, and children with hearing impairement experience more postural instability. Research by Suasu and colleagues (14) on children with typical development and children with hearing impairement between the ages of 7 and 10 years, by using force platform showed that the sway of the postural control of children with SNHL is more than the sway in children with typical development and these children may have sensory organization deficit. Schwab *et al.*, (8) by using posturography system concluded that there was a difference between the balance function of children with normal hearing and deaf children. Cushing and colleagues (15) found that deaf children with profound SNHL receiving cochlear implant were experiencing dysfunction in their static and dynamic balance abilities. Potter and Silverman (16) showed that a high percentage of children with SNHL had vestibular hypofunction and poor static balance. Rine *et al.*, (17) supported the idea that children with SNHL regardless of the results of vestibular tests, have immature static and dynamic balance response. Ming-Wei Huang *et al.*, (18) with research on deaf adolescents with long-term use of cochlear implants showed that the static balance in these children is worse than children with normal hearing. Melo and colleagues (19) by their research on children with SNHL concluded that these children had poorer postural control as compared with normal hearing peers. Heinz-Dieter Kluenter *et al.*, (20) by research on deaf adult candidates for cochlear implants showed that their control posture was significantly worse than healthy adults, and even after the cochlear implant surgery, continued to remain impaired.

Research also has shown that the sensory effectiveness of children with SNHL is lower than children with normal hearing (21,22). Rine and colleagues (22) by using posturography reported on sensory organization deficit of postural control in children with SNHL and concurrent vestibular impairment. In their research, the children with SNHL achieved abnormally low scores on all sensory effectiveness ratios which support the idea that children with SNHL and a concurrent vestibular deficit have a sensory organization deficit that warrants intervention.

In the present study, a significant difference was seen between the children with typical development and deaf children with regard to scores for visual and vestibular ratio and visual preference that is consistent with the above-mentioned studies. However, no significant difference was observed between 2 groups with regard to the score for the somatosensory ratio of sensory organization test, which suggests the somatosensory substitution process that could be due to probable early intervention regarding these children.

Maintaining the balance depends on the interaction of different components, including visual, vestibular, and proprioceptive sense, and deaf children have learned to make up for the deficit in postural control with other systems responsible for balance. The effectiveness of the somatosensory system in postural control emerges by the time a child reaches 3 years of age and the effectiveness of the visual system in postural control in children younger than 7.5 years of age is immature (23). This is when most deaf children with vestibular hypoactivity since their birth fail in conditions associated with somatosensory and visual re-weighting and their ratio scores of visual and somatosensory are significantly lower than their peers without vestibular hypoactivity despite the lack of any evidence showing visual and somatosensory deficit (24). This shows that due to interdependence of senses to each other (22,25), the loss of vestibular function from the time of birth, may impaire the development of functional effectiveness of other sensory components in interactive behaviors of these senses with vestibular input (such as postural control) (22) and as a result, the ability to compensate for vestibular dysfunction gets impaired (24).

On this basis, the deaf children participating in this study, to compensate for postural control loss, were dependent on the information from other systems responsible for the balance, i.e., somatosensory and visual systems. The sensory organization posturography test helps to identify the deficit area and guide for rehabilitation programs. Therefore, the vestibular deficit of these children was not a serious impediment to their normal activities. Research has shown that for children with SNHL and a concurrent vestibular deficit, participation in exercise interventional programs improved sensory organization for postural control and halted the progressive motor development delay (22). Hence, the need to examine the postural control through longitudinal studies to identify areas of sensory deficits that have led to poor balance function, and carrying out early interventions to address the balance deficit in these children are emphasized. Also, since the vestibular function of these children was not available, it is suggested that their vestibular function is evaluated through valid vestibular tests. This issue was the main limitation of this study.

Acknowledgment

Authors of this article express their sincere gratitude to the children and their families for participating in this study.

References

1. De Kegel A, Dhooge I, Cambier D, Baetens T, Palmans T, Van Waelvelde H. Test–retest reliability of the assessment of postural stability in typically developing children and in hearing impaired children. Gait Posture 2011;33:679-85.
2. Derlich M, Kręcisz K, Kuczyński M. Attention demand and postural control in children with hearing deficit. Res Dev Disabil 2011;32:1808-13.
3. Laufer Y, Ashkenazi T, Josman N. The effects of a concurrent cognitive task on the postural control of young children with and without developmental coordination disorder. Gait Posture 2008;27:347-51.
4. Bernard-Demanze L, Dumitrescu M, Jimeno P, Borel L, Lacour M. Age-related changes in posture control are differentially affected by postural and cognitive task complexity. Curr Aging Sci 2009;2:135-49.
5. Suarez H, Angeli S, Suarez A, Rosales B, Carrera X, Alonso R. Balance sensory organization in children with profound hearing loss and cochlear implants. International J Pediatr Otorhinolaryngol 2007;71:629-37.
6. Wong T, Leung E, Poon C, Leung C, Lau B. Balance performance in children with unilateral and bilateral severe-to-profound-grade hearing impairment. Hong

Kong Physiother J 2013;31:81-7.

7. Keshner EA, AK G. Postural Abnormalities in Vestibular Disorders. In: Herdman SJ, Clendaniel R, eds. Vestibular rehabilitation. 4th ed. Philadelphia: FA Davis, 2014:85-109.
8. Schwab B, Kontorinis G. Influencing factors on the vestibular function of deaf children and adolescents-evaluation by means of dynamic posturography. Open Otorhinolaryngol J 2011;5:1-9.
9. Herdman SJ, SL W. Physical Therapy Treatment of Vestibular Hypofunction. In: Herdman SJ, R C, eds. Vestibular rehabilitation. 2nd ed. Philadelphia: FA Davis, 2014:394-431.
10. Liao HF, Mao PJ, Hwang AW. Test-retest reliability of balance tests in children with cerebral palsy. Dev Med Child Neurol 2001;43:180-6.
11. Ebrahimi A-A, Movallali G, Jamshidi A-A, Haghgoo HA, Rahgozar M. Balance Performance of Deaf Children With and Without Cochlear Implants. Acta medica Iranica. 2016;54(11).
12. Fleiss JL. Analysis of data from multiclinic trials. Control Clin Trials 1986;7:267-75.
13. Geldhof E, Cardon G, De Bourdeaudhuij I, Danneels L, Coorevits P, Vanderstraeten G, et al. Static and dynamic standing balance: test-retest reliability and reference values in 9 to 10 year old children. Eur J Pediatr 2006;165:779-86.
14. Monteiro AM, de França Barros J, de Sousa BM. Postural control in children with typical development and children with profound hearing loss. Int J Gen Med 2012;5:433-9.
15. Cushing SL, Chia R, James AL, Papsin BC, Gordon KA. A test of static and dynamic balance function in children with cochlear implants: the vestibular olympics. Arch Otolaryngol Head Neck Surg 2008;134:34-8.
16. Potter CN, Silverman LN. Characteristics of vestibular function and static balance skills in deaf children. Phys Ther 1984;64:1071-5.
17. Rine RM, Lindeblad S, Donovan P, Vergara K, Gostin J, Mattson K. Balance and Motor Skills in Young Children With Sensorineural Hearing Impairment: A Preliminary Study. Pediatric Physical Therapy. 1996;8(2):55-61.
18. Huang MW, Hsu CJ, Kuan CC, Chang WH. Static balance function in children with cochlear implants. Inte J Pediatr Otorhinolaryngol 2011;75:700-3.
19. Melo RdS, Lemos A, Macky CFdST, Raposo MCF, Ferraz KM. Postural control assessment in students with normal hearing and sensorineural hearing loss. Braz J Otorhinolaryngol 2015;81:431-8.
20. Kluenter H-D, Lang-Roth R, Guntinas-Lichius O. Static and dynamic postural control before and after cochlear implantation in adult patients. Eur Arch Otorhinolaryngol 2009;266:1521-5.
21. Gheysen F, Loots G, Van Waelvelde H. Motor development of deaf children with and without cochlear implants. J Deaf Stud Deaf Educ 2008;13:215-24.
22. Rine RM, Braswell J, Fisher D, Joyce K, Kalar K, Shaffer M. Improvement of motor development and postural control following intervention in children with sensorineural hearing loss and vestibular impairment. Int J Pediatr Otorhinolaryngol 2004;68:1141-8.
23. Rine RM. Management of the Pediatric patient with Vestibular Hypofunction. In: Herdman S, editor. Vestibular Rehabilitation, Contemporary Perspectives in Rehabilitation Series. 3rd ed. Philadelphia: FA Davis, 2007:360-70.
24. Rine RM, Wiener-Vacher S. Evaluation and treatment of vestibular dysfunction in children. NeuroRehabilitation 2013;32:507-18.
25. Jacot E, Van Den Abbeele T, Debre HR, Wiener-Vacher SR. Vestibular impairments pre-and post-cochlear implant in children. Int J Pediatr Otorhinolaryngol 2009;73:209-17.