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BALANCE AND VESTIBULAR DEFICITS IN CHILDREN WITH PROFOUND UNILATERAL HEARING IMPAIRMENT

Original Research

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ABSTRACT

Background: Hearing loss is among the most prevalent sensory impairments, significantly impacting communication, spatial awareness, and motor coordination. Unilateral hearing loss (UHL) often remains underdiagnosed in ENT screenings despite its known association with vestibular dysfunction. The vestibular system plays a crucial role in balance by integrating sensory input from visual, proprioceptive, and auditory pathways. This study aimed to determine the prevalence and association between balance impairments and vestibular deficits in children with profound unilateral sensorineural hearing loss (SNHL).

Objective: To assess the frequency and correlation of balance and vestibular dysfunction in children with profound unilateral SNHL.

Methods: A cross-sectional study was conducted among 68 children (33 males, 35 females) aged 8–15 years, recruited from special education schools and ENT clinics. Dynamic balance was assessed using the Pediatric Berg Balance Scale (PBBS), a 14-component test, while static balance and vestibular function were evaluated through the Pediatric Clinical Test of Sensory Interaction on Balance (P-CTSIB) and the Vestibulo-Ocular Reflex (VOR) assessment. Statistical analysis was performed using SPSS version 25, with chi-square tests applied to determine associations between balance deficits and vestibular impairments.

Results: The mean age of participants was 10.57 ± 2.083 years. A significant association ($p < 0.05$) was observed between vestibular dysfunction and balance deficits. Overall, 68% of children exhibited major impairments in maintaining both static and dynamic balance. In P-CTSIB Conditions 5 and 6, where vestibular input was isolated, the Phi and Cramér's V value was 0.624, indicating a strong correlation. VOR testing revealed abnormal compensatory eye movements in 36.7% of children, further confirming vestibular dysfunction.

Conclusion: Children with profound unilateral SNHL exhibited significant balance deficits and vestibular dysfunction. These findings highlight the need for routine vestibular screening in children with hearing impairment to facilitate early intervention and improve motor function.

Keywords: Balance disorders, Hearing loss, Pediatric vestibular assessment, Postural stability, Sensorineural hearing loss, Unilateral hearing impairment, Vestibular dysfunction.

INTRODUCTION

Hearing plays a crucial role in cognitive and behavioral development, allowing individuals to perceive and interpret sounds across a range of frequencies. Normal auditory function ensures awareness of environmental stimuli and supports effective communication, social interaction, and motor coordination. Hearing impairments, particularly profound unilateral hearing loss, can significantly disrupt these fundamental abilities, leading to difficulties in speech perception, spatial awareness, and balance control. The global prevalence of hearing loss varies, with estimates ranging between 4.6% and 8.8% in Southeast Asia. Moderate to severe hearing loss affects approximately six in 1000 individuals, while nearly 10% experience profound hearing loss (1,2). Recognized as the third leading cause of disability worldwide, hearing loss may be partial or complete, affecting one or both ears due to aging, genetic predisposition, environmental noise exposure, infections, chemical imbalances, or traumatic injuries (2,3). Hearing impairments are classified based on the affected anatomical structures. Conductive hearing loss arises from obstructions in the external or middle ear and is often reversible through medical or surgical interventions (1,2). Sensorineural hearing loss (SNHL), on the other hand, results from damage to the inner ear or auditory nerve and is typically irreversible, affecting speech comprehension and overall auditory processing (2,3). Mixed hearing loss involves a combination of both conductive and sensorineural components, necessitating multifaceted treatment approaches (2,4). Beyond its role in auditory perception, the inner ear houses the vestibular system, which integrates sensory inputs from visual, proprioceptive, and auditory modalities to maintain balance and spatial orientation (3,5). The vestibular nerve, a component of the eighth cranial nerve, transmits signals essential for equilibrium, coordinating postural adjustments and reflexive motor responses to head movements (1,6). Three primary motor reflexes originate from the vestibular system: the vestibulocolic reflex (VCR), which stabilizes neck posture; the vestibulo-ocular reflex (VOR), which maintains visual stability; and the vestibulospinal reflex (VSR), which regulates body orientation and postural control (4-6). These reflexes are commonly assessed through Vestibular Evoked Myogenic Potential (VEMP) testing for VCR function, as well as caloric and rotatory chair testing for VOR evaluation (3,4,6). Given the anatomical and functional interdependence of the auditory and vestibular systems, individuals with hearing loss often experience concurrent vestibular dysfunction, leading to impaired postural stability and increased risk of falls (4,7).

The vestibular system comprises three semicircular canals and two otolith organs, the utricle and saccule, which detect angular and linear accelerations, respectively (6,8). Spatial hearing relies on the integration of binaural and monaural cues, with interaural timing (ITD) and level differences (ILD) playing a key role in sound localization (2,8). Individuals with profound unilateral hearing loss struggle with spatial auditory processing, making it challenging to distinguish sounds in noisy environments, which further impairs communication, social interaction, and academic performance (5,6,8). Adaptive strategies, such as favoring the better-hearing ear, can partially mitigate these difficulties, but significant deficits often persist (5,8). Medical interventions, including corticosteroid therapy and cochlear implantation, aim to restore auditory function by directly stimulating the auditory nerve through electrodes implanted in the cochlea, thereby improving speech perception and sound awareness (7,9,10). However, even with cochlear implants, vestibular dysfunction remains a significant concern, particularly in children, where balance deficits can lead to developmental delays in motor skills such as standing, walking, and maintaining posture (7,11,12). The vestibular system undergoes maturation over time, with young children initially relying on visual input for balance before gradually shifting toward somatosensory and vestibular reliance in adulthood (5,12,13). This transition highlights the necessity of early intervention in children with hearing impairments to support motor and cognitive development.

Early hearing screening programs have been widely implemented to facilitate timely diagnosis and intervention. Many countries have established newborn and childhood screening protocols to detect hearing loss at an early stage. The United Kingdom has an extensive long-term screening program, while the United States mandates school-entry hearing assessments and recommends additional screenings at ages 4, 5, 6, 8, and 10 (10,13-15). Hearing loss in children is frequently associated with infections, neural damage, or vestibular abnormalities, further underscoring the need for comprehensive auditory and vestibular evaluations (9,11). Research has consistently demonstrated that children with profound SNHL experience delays in motor milestones, including independent walking and head control, which can negatively impact overall functional development (9,11). Studies have established a strong correlation between the severity of hearing loss and the degree of vestibular impairment, further reinforcing the critical need for early assessment and intervention (2,12). McSweeny et al. (2021) reported that children with unilateral hearing loss and bilateral cochlear implants exhibited significant balance impairments, which in turn affected cognitive function and academic performance (2,8,17). Similarly, Karakoc et al.

(2021) and Melo et al. (2021) identified motor development delays and vestibular deficits in children with unilateral hearing loss, further emphasizing the need for specialized clinical evaluations (14,16,17). A Toronto-based study revealed that approximately 40% of children with hearing loss also had vestibular dysfunction, which negatively impacted memory retention, speech acquisition, and academic success (1,8). Moreover, another study highlighted vestibular deficits in children with unilateral hearing loss, particularly in cases of cochlear nerve deficiency, while study emphasized the necessity of incorporating vestibular assessments into routine clinical practice (16,17). Another study demonstrated significant balance impairments in children with hearing loss, linking these deficits to an increased risk of falls and delayed postural control development (17,9). Despite the growing body of evidence highlighting vestibular deficits in children with hearing loss, routine vestibular screening remains underutilized in clinical practice. Given the significant impact of balance impairments on motor development, social functioning, and academic performance, comprehensive vestibular assessments should be integrated into standard audiological evaluations. This study aims to investigate the prevalence and severity of balance and vestibular deficits in children with profound unilateral hearing impairment, addressing a critical gap in pediatric hearing loss research. By identifying specific vestibular dysfunctions associated with profound unilateral hearing loss, the study seeks to enhance diagnostic accuracy, inform targeted rehabilitation strategies, and ultimately improve functional outcomes for affected children.

METHODS

A cross-sectional study was conducted to evaluate balance and vestibular deficits in children with profound unilateral sensorineural hearing loss (SNHL). The study employed a non-probability convenience sampling technique, with data collected from otolaryngology (ENT) clinics and special education institutions catering to children with hearing impairments. The study population comprised school-going children aged 8 to 15 years, diagnosed with profound unilateral SNHL either by an ENT specialist or based on school registration records. Children who used hearing aids or cochlear implants for unilateral hearing loss, whether congenital or acquired, were included, provided they had been using the device for at least six months to allow for adaptation. Exclusion criteria included children with a history of orthopedic diseases, psychiatric disorders, migraine, seizures, vestibular neuronitis, benign paroxysmal vertigo of childhood, prior ear surgery, bilateral hearing loss, or visual impairment, as these conditions could independently affect balance and vestibular function (18). The sample size was calculated using OpenEpi software, based on an anticipated prevalence of vestibular dysfunction in hearing-impaired children. Using a 95% confidence level, a power of 80%, and a margin of error of 5%, the following formula was applied (19):

$$n = \frac{Z^2 P(1 - P)}{d^2}$$

Where n= is the required sample size, Z= is the standard normal variate (1.96 for 95% confidence level), P= is the estimated prevalence of vestibular dysfunction in hearing-impaired children (assumed at 40% based on previous studies), d= is the margin of error (0.05). Substituting these values, a minimum sample size of 369 children was required for statistical significance. However, due to feasibility constraints, data collection was conducted for the maximum achievable sample (12). Outcome measures included the Pediatric Clinical Test for Sensory Interaction on Balance (P-CTSIB), the Pediatric Berg Balance Scale, and the Vestibulo-Ocular Reflex (VOR) head impulse test. The P-CTSIB assessed static balance by evaluating sensory, vestibular, and somatosensory contributions to postural control under six different conditions, involving variations in surface type (firm or foam) and visual input. The Pediatric Berg Balance Scale, a 14-item tool with a total score of 56, measured dynamic balance through functional tasks such as sitting, standing, turning, and retrieving objects. The VOR head impulse test assessed gaze stability by analyzing compensatory eye movements in response to abrupt head movements, providing an indication of vestibular function (15).

Ethical approval for the study was obtained from the institutional review board (IRB), and informed consent was obtained from guardians or school administration before participation. A structured questionnaire was used to gather information regarding vestibular deficits and balance-related concerns. Standardized balance and vestibular assessments were conducted under controlled conditions, with instructions provided to participants through written explanations, visual demonstrations, or pictorial representations to enhance comprehension. Engagement strategies, such as offering small rewards, were employed to encourage participation and optimize test performance (11). Data were analyzed using SPSS version 25. Descriptive statistics were calculated for continuous variables, while categorical data were examined using the chi-square test to explore associations between balance deficits and vestibular impairments.

Results were presented in the form of tables and graphs for clarity. Intra- or inter-rater reliability was not assessed, which may have introduced some variability in test administration. Throughout the study, strict confidentiality measures were maintained to protect participant information, and ethical considerations were adhered to in compliance with research guidelines (14).

RESULTS

The study evaluated 80 school-going children aged 8 to 15 years diagnosed with unilateral sensorineural hearing loss (SNHL), with a mean age of 10.57 ± 2.083 years. The majority of participants were 10 years old. Gender distribution was nearly equal, with 50.7% female and 49.3% male. Right-sided hearing impairment was more prevalent, affecting 55.1% of participants, while 44.9% had left-sided impairment. Regarding treatment history, 15.9% had never received any form of treatment, 30.4% had been under treatment for less than a year, and 53.6% had been receiving treatment for more than a year. Most participants (69.6%) were treated at ENT clinics, whereas 30.4% were enrolled in special education institutions. Balance and vestibular function were assessed using the Pediatric Clinical Test of Sensory Interaction on Balance (P-CTSIB) and the Pediatric Berg Balance Scale (PBBS). In Condition 1 (eyes open, firm surface), most participants maintained balance for 30 seconds, though 26 exhibited instability. The most challenging condition was Condition 6 (eyes closed, foam surface with visual conflict), where 24 children were unable to assume the position, and only 4 successfully maintained balance for 30 seconds. PBBS results indicated that 16 children were classified as low fall risk, 47 as moderate risk, and 6 as high risk. Participants with delayed diagnosis and a lack of vestibular rehabilitation exhibited the most pronounced balance deficits, reinforcing the importance of timely intervention.

Vestibulo-ocular reflex (VOR) assessments further revealed significant vestibular impairments. Horizontal saccades were impaired in 14 children, while 15 demonstrated deficits in vertical saccades. Smooth pursuit impairments were observed in 23 children, and 25 exhibited abnormal head impulse test results, indicating difficulties in compensatory eye movements. Statistical analysis demonstrated a significant association ($p < 0.05$) between balance deficits and vestibular impairments across all P-CTSIB conditions and PBBS scores. The strongest association was observed in Condition 6 ($\Phi = 0.601$), where participants relied solely on vestibular input. High fall-risk participants displayed greater instability, particularly in visually conflicting conditions, suggesting that vestibular dysfunction played a critical role in postural control deficits. A comparative analysis between right- and left-sided unilateral sensorineural hearing loss (SNHL) revealed notable differences in balance and vestibular deficits. Participants with right-sided impairment exhibited greater instability across various test conditions, particularly in visually conflicting scenarios such as Condition 6 of the Pediatric Clinical Test of Sensory Interaction on Balance (P-CTSIB). A higher proportion of right-sided impairment cases demonstrated abnormal responses in the Vestibulo-Ocular Reflex (VOR) assessments, including deficits in smooth pursuit and horizontal saccades. This may be attributed to the dominance of the left cerebral hemisphere in spatial processing and motor control, which could lead to greater reliance on vestibular input from the right ear. In contrast, participants with left-sided impairment displayed relatively better balance control, particularly in static balance conditions, suggesting a potential compensatory mechanism in the right hemisphere. These findings highlight the lateralization of auditory and vestibular function and suggest that the side of hearing impairment may influence postural control, warranting further investigation into tailored rehabilitation strategies based on laterality.

Table 1 Association of balance deficits and vestibular impairments

PBBS	**Condition 1**					**P value**	**Phi & Cramours**
Categories	Unable to assume position	Maintain position <10s	Maintain position <20s	Maintain position 30s with instability	Maintain position 30s no instability	<0.05	0.624
High Risk of fall	0(0.0%)	2(66.7%)	3(12.5%)	1(38.8%)	0(0.0%)		
Moderate risk of fall	0(0.0%)	1(33.3%)	20(83.3%)	18(69.2%)	7(46.7%)		
Low risk of fall	0(0.0%)	0(0.0%)	1(4.2%)	7(26.9%)	8(53.3%)		

INSIGHTS-JHR
INSIGHTS-JOURNAL OF HEALTH AND REHABILITATION

PBBS	**Condition 2**					**P value**	**Phi & Cramours**
Categories	Unable to assume position	Maintain position <10s	Maintain position <20s	Maintain position 30s with instability	Maintain position 30s no instability		
High Risk of fall	1(1.5%)	2(11.8%)	2(33.8%)	1(32.4%)	0(0.0%)		
Moderate risk of fall	0(0.0%)	6(13.0%)	20(43.5%)	13(28.3%)	7(15.2%)		
Low risk of fall	0(0.0%)	0(0.0%)	1(4.3%)	8(36.4%)	7(50.0%)		
PBBS	**Condition 3**						
Categories	Unable to assume position	Maintain position <10s	Maintain position <20s	Maintain position 30s with instability	Maintain position 30s no instability		
High Risk of fall	2(33.3%)	2(33.3%)	2(33.3%)	0(0.0%)	0(0.0%)		
Moderate risk of fall	0(0.0%)	17(30.0%)	14(37.0%)	12(26.1%)	3(6.5%)		
Low risk of fall	0(0.0%)	1(6.3%)	5(31.3%)	4(25.0%)	6(37.5%)		
PBBS	**Condition 4**						
Categories	Unable to assume position	Maintain position <10s	Maintain position <20s	Maintain position 30s with instability	Maintain position 30s no instability		
High Risk of fall	0(0.0%)	4(66.7%)	1(16.7%)	1(16.7%)	0(0.0%)		
Moderate risk of fall	0(0.0%)	22(47.8%)	13(28.3%)	7(31.3%)	4(43.8%)		
Low risk of fall	0(0.0%)	2(12.5%)	2(12.5%)	5(31.3%)	7(43.8%)		
PBBS	**Condition 5**						
Categories	Unable to assume position	Maintain position <10s	Maintain position <20s	Maintain position 30s with instability	Maintain position 30s no instability		
High Risk of fall	0(0.0%)	5(83.3%)	1(16.7%)	0(0.0%)	0(0.0%)		
Moderate risk of fall	7(15.2%)	18(39.1%)	12(26.1%)	8(17.4%)	1(2.2%)		
Low risk of fall	0(0.0%)	4(25.0%)	1(6.3%)	6(37.5%)	5(31.3%)		
PBBS	**Condition 6**						
Categories	Unable to assume position	Maintain position <10s	Maintain position <20s	Maintain position 30s with instability	Maintain position 30s no instability		
High Risk of fall	4(66.7%)	1(16.7%)	1(16.7%)	0(0.0%)	0(0.0%)		
Moderate risk of fall	18(39.1%)	14(30.4%)	8(17.4%)	5(10.9%)	1(2.2%)		
Low risk of fall	2(12.5%)	3(18.8%)	0(0.0%)	8(50.0%)	3(18.8%)		

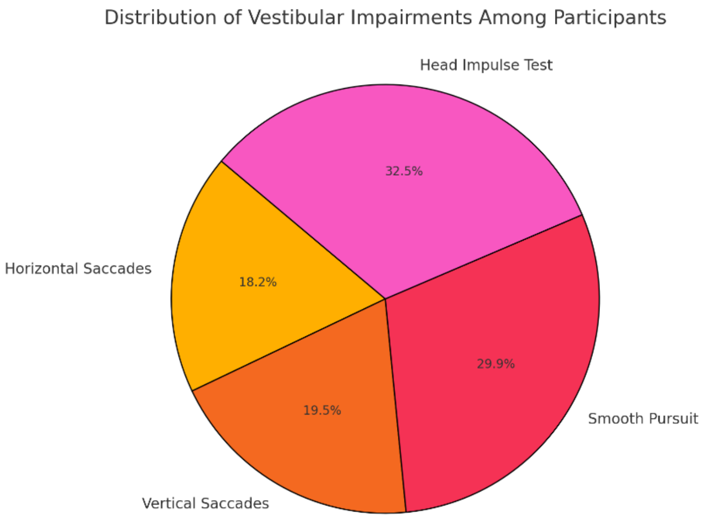

Figure 2 Distribution of Vestibular Impairments Among Participants

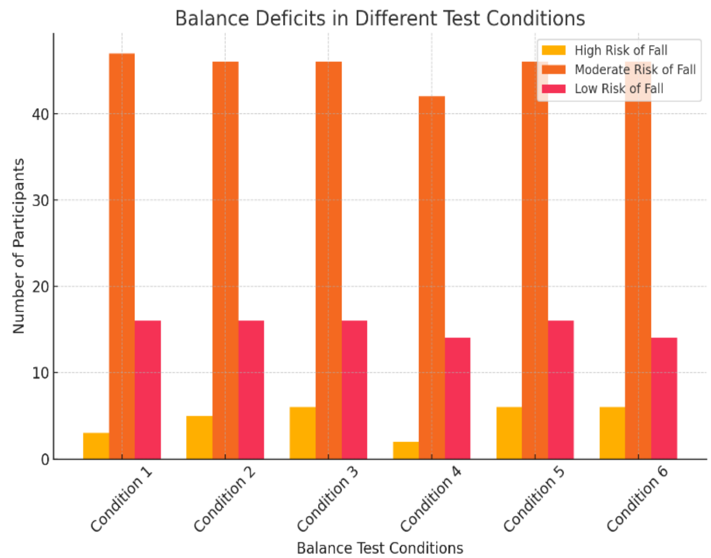

Figure 1 Balance Deficits in Different Test Conditions

DISCUSSION

The study assessed balance and vestibular deficits in children with profound unilateral sensorineural hearing loss (SNHL), revealing that a significant proportion exhibited moderate to severe balance impairments. The findings align with previous research indicating a strong association between unilateral hearing impairment and vestibular dysfunction, with a considerable number of participants displaying postural instability and impaired gaze stabilization. The prevalence of moderate vestibular deficits among participants reinforces the well-documented relationship between auditory and vestibular systems, as both share anatomical and neural pathways. Children with less than six months of treatment demonstrated the highest risk of falls, suggesting that early intervention and rehabilitation play a crucial role in mitigating balance impairments. School-going children actively engaged in physical activities exhibited better balance control compared to those in restricted environments, emphasizing the role of environmental stimulation in motor development (20). Postural instability was most pronounced in visually conflicting conditions, as observed in the eyes-closed foam surface test, highlighting the reliance of children with SNHL on visual and somatosensory cues for balance compensation. These findings support previous evidence that children with hearing loss develop adaptive postural control mechanisms to counteract vestibular deficits. The positive smooth pursuit and head impulse test results further reinforce the vestibular origin of balance dysfunction, as these assessments directly evaluate vestibulo-ocular reflex integrity. Additionally, findings suggest that children with bilateral hearing loss generally exhibit poorer balance performance compared to those with unilateral impairment, indicating that even partial auditory input may provide some degree of stabilization (21).

A key strength of the study lies in its assessment of multiple domains of balance, utilizing standardized tests that evaluated both static and dynamic stability under different sensory conditions. The inclusion of children with various durations of treatment allowed for an evaluation of the impact of vestibular rehabilitation and auditory compensation over time. However, certain limitations must be acknowledged. The study utilized a cross-sectional design, which restricts the ability to establish causation between unilateral hearing loss and balance deficits. The sample size, though adequate for statistical analysis, may limit the generalizability of the findings to broader populations. Additionally, the lack of intra- and inter-rater reliability assessments introduces a potential source of measurement variability. Future studies should incorporate longitudinal designs to track the progression of balance function over time and assess the long-term efficacy of vestibular rehabilitation programs. Expanding the sample to include children with different degrees of unilateral hearing loss and comparing their balance performance with normal-hearing peers could provide further insights into the mechanisms underlying vestibular dysfunction (22). The study highlights the importance of integrating vestibular assessments into routine audiological evaluations for children with hearing loss. Early identification of balance impairments may facilitate timely interventions, improving motor development, postural stability, and overall functional outcomes. Implementing structured vestibular rehabilitation

INSIGHTS-JHR
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programs tailored to the specific deficits identified in children with unilateral SNHL could enhance their ability to adapt to sensory challenges and reduce the risk of falls. Given the significant impact of vestibular dysfunction on daily activities, educational performance, and quality of life, addressing balance deficits in children with hearing loss should be prioritized in clinical and rehabilitation settings (23,24).

CONCLUSION

The findings of this study underscore the significant impact of profound unilateral hearing impairment on vestibular function and balance control in children. The presence of balance deficits and an increased risk of falls highlight the crucial role of the vestibular system in postural stability and motor development. These impairments not only affect physical coordination but also contribute to broader developmental challenges, including social and cognitive difficulties. The results emphasize the need for early identification and targeted interventions to mitigate the effects of vestibular dysfunction in children with hearing loss. Integrating vestibular assessments into routine audiological evaluations and implementing rehabilitation strategies can enhance motor function, reduce fall risk, and improve overall quality of life, ensuring better long-term developmental outcomes.

AUTHOR CONTRIBUTIONS

Author	Contribution
Ateeb Arooj*	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Anum Farooq	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Rimsha Munawar	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Tehniat Fatima Zafar	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Amna Bibi	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Aaleen Fatima	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published
Asma Bhatti	Contributed to study concept and Data collection Has given Final Approval of the version to be published
Noor Fatima	Writing - Review & Editing, Assistance with Data Curation

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