

Characteristics of Vestibular Function and Static Balance Skills in Deaf Children

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The vestibular function and static balance skills of 34 children who had sensori-neural deafness, ranged in age from 5 to 9 years, and attended the Western Pennsylvania School for the Deaf were compared with normative data. The purpose of the investigation was to describe the characteristics of vestibular function and static balance skill in deaf children who had no other known handicaps. We explored the relationship between these two characteristics. The Southern California Postrotary Nystagmus test and the Standing Balance subtests (eyes open and closed) of the Southern California Sensory Integration tests were used to evaluate the deaf children. Comparison of study results with norms revealed a significant difference in duration of postrotary nystagmus between hearing and deaf children. Balance skills were not significantly related to level of vestibular response. No significant sex differences were found in the vestibular or balance status of the deaf children. The differences in the characteristics of vestibular function and static balance skills in the deaf children compared with hearing children are important to therapists working with the deaf. Therapists should consider that these differences exist when they identify those deaf children with learning or other sensory-motor problems. Therapists familiar with the use of the Southern California Sensory Integration tests and Southern California Postrotary Nystagmus test must be cautious in using these tests with the deaf until they are standardized for this group.

Key Words: *Deafness, Kinesthesia, Vestibular function tests.*

Vestibular function and balance skills of deaf children are of interest to physical or occupational therapists working with this group because the characteristics of these functions may differ from those of children with unimpaired hearing. Few studies have been conducted comparing balance skills of the deaf with those of hearing children. Studies investigating vestibular function in the deaf have found abnormalities compared with hearing subjects. To interpret the results of testing in deaf children, therapists must know the characteristics of vestibular function and balance skills and whether these characteristics are related to motor and learning performance in the deaf. Because motor and learning problems have been associated with deficits in these areas, identifying the characteristics of vestibular function and balance skill in the deaf and discussing the relationship between them will be helpful to therapists.¹

Some studies concerning the deaf have not used adequate controls for age, etiology of deafness, and IQ; others have not clearly defined the method for investigating balance skill or vestibular function. Two studies by Myklebust^{2,3} and one by

Scanlon and Goetzinger⁴ demonstrated that severely deaf children, particularly children deafened by meningitis, performed more poorly on locomotor tests than children with unimpaired hearing. The authors of the latter study did not control for factors that could also influence balance such as IQ, learning disabilities, or other neurological problems in selecting their subjects.

Boyd found that deaf boys have less skill than hearing boys in dynamic balance.⁵ He stated, "This deficiency on the part of the deaf can be attributed to vestibular, cerebellar, or central nervous system impairment." The relationship between vestibular and balance deficiencies, however, was not specifically investigated. Boyd also reported no significant differences in static equilibrium ability with regard to etiology of deafness.⁵ McCarron and Ludlow's investigation of balance in those deafened by viral causes reported that 46 percent had severe problems, 2 percent had moderate problems, and 52 percent had standard balance.⁶ The distinction between these categories of balance problems was undefined. More recently, Lindsey and O'Neal found that deaf children performed more poorly in static and dynamic balance skills than hearing children.⁷ Furthermore, the elimination of visual input on static balance tasks increased the difficulty for the deaf more than for the hearing children.

Studies of the vestibular abilities of deaf children have used a wide range of methods and produced varying results. Using rotary and caloric vestibular tests, Arnvig found absent nystagmus in 19 percent of deaf children and abnormal nystagmus in 22 percent.⁸ He also found normal vestibular function

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in most patients with severe inherited hearing loss or deafness acquired in the prenatal or perinatal period. Vestibular function was abolished, however, in most cases of hearing loss acquired after birth.⁸ Vestibular function is frequently abolished in children deafened by meningitis.⁹⁻¹¹ Rosenblut et al identified absent nystagmus in 25 percent and abnormal nystagmus in 23 percent of their sample of deaf children with various etiologies.¹²

Using a rotary test, Guilder and Hopkins found that the mean postrotary nystagmus duration for their hearing group was 19.6 seconds and 9.95 seconds for the deaf group.⁹ The range for the hearing group was 9 to 34 seconds and 0 to 26 seconds for the deaf group. These findings compare favorably with norms established by Ayres who found a mean postrotary nystagmus duration of 19 seconds and a range of 1 to 40 seconds in a sample of hearing children.¹³

Some researchers have suggested that vestibular function affects gross motor development. Deaf infants with vestibular as well as cochlear damage are delayed in achieving head control, independent sitting, and walking.¹¹

Two studies have investigated sex differences in vestibular function of hearing children. Ayres found that girls showed a significantly shorter duration of nystagmus after rotation than boys.¹³ Kimball, however, reported that postrotary nystagmus is a consistent measure unaffected by sex.¹⁴ In the Standing Balance subtests (eyes open and closed) of the Southern California Sensory Integration tests (SCSIT) developed by Ayres, no sex differences have been noted.¹⁵

The vestibular apparatus and cochlea are closely related both anatomically and developmentally. A noxious influence prenatally, perinatally, or postnatally may cause damage to one or both systems.¹⁶ Therapists should be familiar with the vestibular reflexes involved in postural control. Physical or occupational therapists have not been traditionally involved in the multidisciplinary team working with the deaf child.¹⁷ Therefore, little research has been reported by therapists concerning motor development in this group. We located only two published studies conducted by therapists, and these concerned balance skill in the deaf.^{7,18} No information concerning vestibular function had been reported by therapists, and the relationship of vestibular function to balance has not been discussed. Clinical observations of these functions made by therapists treating deaf children should be substantiated by more research.

The purpose of this study was to investigate vestibular dysfunction in the deaf, the characteristics of static balance skill, and the relationship of vestibular function to static equilibrium in school-aged deaf children. Because therapists often assess vestibular function and balance as part of their evaluations to determine whether a child needs to be treated, knowing the characteristics of these functions in deaf children who have no other impairments is important. This investigation used practical standardized tests to identify the predominance of vestibular dysfunction and static balance deficits in children with sensorineural deafness. We chose the Standing Balance subtests of the SCSIT and the Southern California Postrotary Nystagmus Test (SCPRNT) for their established reliability with healthy children and current use by therapists in identifying children who could benefit from treatment. A dynamic equilibrium test was not included in this study as one does not exist as part of the SCSIT battery.

METHOD

Sample

The sample consisted of deaf students attending the Western Pennsylvania School for the Deaf between the ages of 5.0 and 8.11 years and with an IQ above 85. The sample was limited to this age group because it represents the standardized range for these tests. The IQ was determined in individual testing with the Leiter,¹⁹ Wechsler PPSI,²⁰ or Merrill-Palmer²¹ test administered by a certified school psychologist. All children were severely or profoundly deaf. Those children with known neurological impairments, such as cerebral palsy or learning disabilities, and any orthopedic handicaps were excluded from the study. Although not all learning-disabled children in this sample may have been identified, we had reasonable confidence that they were excluded from the study sample. Most of these children had been at this school since the age of 2 years, and their academic abilities were well known. Deafness in the group was primarily of unknown congenital causes or postnatally acquired as a result of viral or unknown causes. The mean age of the sample was 6.1 years.

Thirty-four (34) deaf students met the above criteria. Of these, 16 were boys and 18 were girls. The IQ range of these students was 85 to 151. Hearing loss in the better ear ranged from 55 to 120 dB. The average hearing loss was 100.5 dB.

Procedure

We used the SCPRNT to assess the vestibular function of each child.¹³ The child sat cross-legged on a rotating board with the head flexed forward 30 degrees from the vertical position. The 30-degree flexion of the head brought the horizontal semicircular canal parallel with the ground to allow maximum stimulation of this canal during testing. We administered the test by first rotating the child 10 rotations to the left at a constant velocity of 10 rotations in 20 seconds and then stopping the child suddenly. We observed the duration of the resulting nystagmus visually and measured it from cessation of spinning until observable nystagmus was no longer present. After a one-minute rest to allow for decay of the effects of rotation, we repeated the test by rotating the child to the right in a similar manner and measuring the resulting nystagmus. The duration of the induced nystagmus was recorded in seconds. The examiner who was proficient in use of sign language gave all directions simultaneously in sign language and verbally. All children appeared to understand the directions and cooperated well.

We recorded the resulting vestibular response as either "normal," "absent," or "hypoactive" as determined by comparing the child's duration of observable nystagmus with published standardized norms.¹³ This comparison used standard deviation scores. We defined normal as -1 to $+1$ s from the mean duration of nystagmus in the normative sample, and hypoactive as more than -1 s from this mean. No excessive duration of nystagmus that would have been considered hyperreactive (greater than $+1$ s above the mean duration of nystagmus in the normative sample) was noted in the deaf group. This test had been standardized on 226 hearing children, 111 boys and 115 girls between 5.0 and 8.11 years of age.¹³ Test-retest stability for hearing children has shown

duration of nystagmus as measured by the SCPRNT to be statistically reliable and clinically respectable.^{13, 14}

Standing balance with eyes open and closed was tested using the Standing Balance subtests of the SCSIT. We administered the Standing Balance subtests before the SCPRNT to eliminate any residual effects that the rotation test might have had on the child's equilibrium. Each child was given two trials on each leg on both Standing Balance with Eyes Open (SBO) and Standing Balance with Eyes Closed (SBC). We asked the child to stand looking straight ahead with the arms folded, elbows flexed, and hands tucked in and held near the chest. The child was then instructed to lift the right foot. We recorded the number of seconds that the child was able to balance. We began timing when one foot was lifted and ended when the child demonstrated imbalance. We defined imbalance as the child placing the lifted foot on the floor again, extending a hand to regain balance, hopping, or moving the weight-bearing foot.¹³

We repeated the two-trial procedures on the left foot. The interval between trials for both SBO and SBC was sufficient; the child assumed a stable position with both feet on the ground and hands at sides before attempting a second trial.

After the SBO trials, the child performed two trials on each leg for SBC. We instructed the child to stand facing forward with arms folded, elbows flexed, and hands tucked in and held near the chest. We asked the child to close both eyes and then lift one foot. Time was recorded as described for SBO. The child's ability to balance on SBO and SBC was determined to be normal or abnormal by comparison with standardized norms. The lowest score defined as normal was -1.00 s from the mean of the number of seconds that the normative sample was able to balance on one leg. Abnormal was considered to be more than -1.00 s from this mean. The better of the two trials in each case was used for comparison. The standardization sample consisted of 807 children between the ages of 5.0 and 8.11 years, 398 boys and 409 girls. The test-retest stability scores ranged from .51 to .62 for SBO and from .24 to .33 for SBC.¹⁵

Data Analysis

A t test was used to compare duration of postrotary nystagmus in the deaf and hearing subjects. Chi-square analysis was used to explore the association between vestibular response to the SCPRNT and Standing Balance subtests. A Pearson product-moment correlation was calculated to determine the relationship between SBO and SBC. The two-tailed t test was used to determine if sex differences existed in vestibular response or the Standing Balance test results.

RESULTS

Vestibular Function

The results indicated that 20 of the 34 deaf children (58.8%) had hypoactive vestibular response. Nearly half (44.1%) had no response to vestibular stimulation. Five (14.7%) showed abnormally low response. Normal response was demonstrated by 14 (41.2%).

The t test comparing scores on the SCPRNT of the deaf children with the normative sample showed a significant difference ($p < .001$) between the two groups. The mean

postrotary nystagmus score for the deaf group was 9.5 seconds, but the mean for the normative sample was 19 seconds (Tab. 1).

Relationship of Vestibular Response and Balance Abilities

With eyes open, 44.1 percent of the deaf children had abnormal standing balance. With eyes closed, 35.3 percent had abnormal balance. Chi-square analysis revealed no significant association between vestibular response to the SCPRNT and standing balance with eyes open or closed. A moderate correlation existed between performance on SBO and SBC as indicated by a Pearson product-moment correlation coefficient of .50 at a .001 level of significance.

The deaf children with no observable nystagmus performed no worse than children with normal or hypoactive vestibular function in regard to standing balance. Of the 15 deaf children with absent vestibular response, 8 (53.3%) had normal balance with eyes open and 7 (46.7%) had abnormal balance. With eyes closed, 9 (60%) had normal balance and 6 (40%) had abnormal balance. Three with abnormal vestibular response had abnormal balance with eyes both open and closed.

Sex Differences

The two-tailed t test revealed no significant differences in vestibular response between boys and girls, although girls tended to have lower vestibular response (Tab. 2). No significant difference was found in standing balance skills with eyes either open or closed between girls and boys using the t test. Table 3 provides a breakdown of the number of boys and girls according to normalcy of vestibular and balance responses.

DISCUSSION

An understanding of vestibular responses is critical to interpreting the results of this study. The vestibular labyrinth consists of two saclike structures (the saccule and utricle) and three semicircular canals (the horizontal, anterior, and posterior). The labyrinth is located deep within the temporal bone and is continuous with the cochlea. The semicircular canals are primarily stimulated by angular acceleration; the otolith organs are stimulated by transient linear acceleration and by changes in head position with respect to gravity. These stimuli evoke phasic and tonic vestibulo-ocular and vestibulo-spinal reflexes, which act on the head and limbs to maintain posture. The vestibulo-ocular reflexes activated in the semicircular canals provide a shift in the angular position of the eyes or head to compensate for movement produced by external stimuli. Postrotary nystagmus is the rhythmic com-

TABLE 1
Comparison of Mean Postrotary Nystagmus Duration in Deaf and Hearing Groups*

Groups	n	$\bar{X}$ (sec)	range (sec)	s
Deaf	34	9.5	0-29	10.0
Hearing	226	19.0	1-40	6.9

* Significant difference between groups: $t = 6.93$; $p < .001$.

TABLE 2
Sex Differences in Vestibular Function and Balance Skill of Deaf Children

Subjects	n	Postrotary Nystagmus			Standing Balance (eyes open)			Standing Balance (eyes closed)		
		$\bar{X}$ (sec)	s	t	MS	s	t	MS	s	t
Girls	18	12.0	11.5	1.34 ^a	-0.64	1.03	0.91 ^a	-0.40	1.08	1.95 ^a
Boys	16	7.40	8.16		-0.99	1.17		-1.13	1.10	
TOTAL	34	9.59	10.0		-0.83	1.10		-0.79	1.09	

^a Not significant.

TABLE 3
Vestibular Function and Static Balance According to Sex

Type of response	Postrotary Nystagmus			Standing Balance (eyes open)			Standing Balance (eyes closed)		
	Boys	Girls	n	Boys	Girls	n	Boys	Girls	n
Normal	7	7	14	10	9	19	13	9	22
Abnormal	2	3	5	6	9	15	3	9	12
Absent	7	8	15	0	0	0	0	0	0

compensatory motion of the eyes that occurs after rotation. Activation of the reflexes in the semicircular canals influences the activity of many muscles throughout the body and contributes to sensations of body position. These reflexes acting on the limb muscles are more variable than those acting on the extraocular or neck muscles, but they also serve to maintain stability of the head in space.¹⁶

The otolith receptors are sensitive to gravity and are thus able to provide neural signals related to the position of the head in relation to the earth. The static reflexes evoked give rise to activation of the extraocular and somatic muscles to attempt to maintain the head in a vertical position.¹⁶

Numerous reflexes, of which those originating in the labyrinth comprise only a part, interact to maintain stable posture. Orientation in space depends to a high extent on input from vestibular receptors, but visual cues are also important. Information is also supplied by impulses from proprioceptors in the joint capsules and impulses from cutaneous exteroceptors, especially those of touch and pressure. These four inputs are integrated at various levels of the nervous system to maintain posture.¹⁶

This study showed that a large percentage of children with sensorineural hearing loss resulting from various etiologies without other handicapping conditions have hypoactive vestibular response. The mean duration of postrotary nystagmus was far below that of hearing children and compares favorably with the study of Guilder and Hopkins who found a mean duration of 9.95 seconds in the deaf using a rotary test to evaluate children deafened by various etiologies.⁹ Also, the range of vestibular response in deaf children compared closely with the findings of this study. We did not specifically investigate the incidence of abnormal vestibular function with respect to etiology because many of the children's hearing losses were the result of unknown causes.

Our study also found that many deaf children have poor static balance skills, but static standing balance was not significantly related to vestibular function. Because of the exten-

sive and complex interconnections of the vestibular system, we expected that subjects with decreased vestibular response as measured by the rotation test would also demonstrate poor standing balance. Also, SBO was only moderately correlated with SBC. Some deaf children seemed to compensate for a lack of vestibular input through use of nonlabyrinthine receptors such as visual and kinesthetic systems to maintain posture. Some children apparently compensated better than others. This finding deserves further study.

Assessing the various functions of the vestibular system has an inherent difficulty. The system's complexity, numerous levels of integration throughout the nervous system, and the lack of recognition of all of its functions make evaluation difficult.¹⁶ Because of interconnections with other sensory systems in vestibular-mediated responses, selectively evaluating an aspect of vestibular function is impossible. Black et al stated, "There are no universally accepted, much less standardized clinical methods for evaluation of the human vestibulo-ocular system."²²

The limitations of clinical tests available to pediatric therapists who wish to evaluate the vestibular system's influence on postural control are many. Several factors must be considered concerning the use of the SCPRNT. This test reflects a limited aspect of vestibular response. It evaluates the integrity of the vestibular system primarily in the horizontal canal assuming that the child's head is fixed at 30-degrees forward flexion. If the child's head deviates, a change in the resulting postrotary nystagmus could occur. In this study, however, any change in the subject's head position was not sufficient to be visually evident to the examiner. Also, Black et al stated that the rotation test may not reflect the functioning of the entire vestibular system.²² Damage to the system may occur peripherally or centrally at any point and may not be reflected by a rotation test.

Duration of nystagmus using the SCPRNT has been shown to be reliable with hearing children.^{13, 14} Reliability of the SCPRNT with other groups, including the deaf for whom

reliability has not been established, merits consideration. A study of reliability of the SCPRNT with learning-disabled children found intrascorer and test-retest stability to be lower than that established for hearing children.²³ Clinicians should be aware of possible variations in deaf children similar to those demonstrated in learning-disabled children.

Limitations using the Standing Balance subtests also must be considered. The quantified measures, SBO and SBC, are frequently used to manifest the integrity of some postural mechanisms. A discrete pattern of vestibular response to linear acceleration cannot be identified with these tests because the final response is determined by integration of information from the otoliths and semicircular canals with input from nonlabyrinthine receptors. These tests, SBO and SBC, cannot be relied on as ideal measures of postural mechanisms. Interpreting the results of these tests is complicated by the interplay between activity from proprioceptors, cutaneous receptors, activity from the labyrinth, and the optical righting reflex in the case of SBO. Less influence from nonlabyrinthine receptors occurs with SBC, which eliminates the effects of visual perception. In factor analyses of the SCSIT, Ayres found that SBC loaded more strongly than SBO on postural-ocular factors.¹³ The moderate test-retest stability for SBO and low test-retest stability for SBC with hearing children is likely to be the result of the large number of converging inputs involved in producing a postural response.

Reliability of the SCSIT must be established for deaf children without other handicapping conditions so that therapists familiar with the SCPRNT and SCSIT can use these tests to identify those deaf children with learning and other neurological problems. Also, vestibular stimulation is advocated as a part of treatment programs for children with learning problems who demonstrate depressed postrotary nystagmus.¹ Further study is needed to determine if and how a treatment program using vestibular stimulation affects deaf children and

if changes in postrotary nystagmus will occur as a result of that treatment. Although the loss of vestibular information can be compensated for relatively easily in the hearing individual,¹⁶ more research needs to be conducted to determine how the lack of vestibular input affects those deaf children who are also learning-disabled, mentally retarded, or developmentally delayed. Before the management of vestibular disorders in these multiple-handicapped children is discussed, additional testing must be done with deaf children free from other handicaps.

CONCLUSIONS

We compared 34 deaf children from the Western Pennsylvania School for the Deaf with Ayres's normative sample regarding vestibular function¹³ and balance skills.¹⁵ A significant difference in the duration of postrotary nystagmus was found between the deaf children and the normative sample. Static balance skills were not significantly related to the type of vestibular function. No significant sex differences were found in vestibular function or static balance skills. Many deaf children seemed to compensate for vestibular deficits through nonlabyrinthine systems, such as visual and kinaesthetic, to maintain static balance with eyes open or closed.

Knowledge of the high incidence of vestibular dysfunction and problems with static balance in deaf children without other handicaps is important information for therapists evaluating and treating deaf children. Therapists using the SCPRNT and SCSIT should be aware that vestibular and balance deficits found in deaf children, unlike similar conditions in hearing children, may not be associated with learning disabilities. Therapists need to be especially cautious in evaluating postural control in the deaf and should rely on additional clinical observations as well as these tests to draw conclusions and plan treatment programs.

REFERENCES

1. Ayres AJ: Sensory Integration and Learning Disorders. Los Angeles, CA, Western Psychological Services, 1976
2. Myklebust HR: Significance of etiology in motor performance of deaf children with special reference to meningitis. *Am J Psychol* 59:249-258, 1941
3. Myklebust HR: The Psychology of Deafness. New York, NY, Grune & Stratton Inc, 1960, pp 180-203
4. Scanlon SL, Goetzing CP: The Heath Rails and Fukuda Vestibular tests with deaf and hearing subjects. *Eye, Ear, Nose, and Throat Monthly* 48:29-39, 1969
5. Boyd J: Comparison of motor behavior in deaf and hearing boys. *Am Ann Deaf* 112:598-605, 1967
6. McCarron LT, Ludlow GC: Sensori-neural deafness and neuromuscular dysfunctions: Considerations for vocational evaluation and job placement. *J Rehabil* 47:59-79, 1981
7. Lindsey D, O'Neal J: Static and dynamic balance skills of eight-year-old deaf and hearing children. *Am Ann Deaf* 121:49-55, 1976
8. Arnvig J: Vestibular function in deafness and severe hardness of hearing. *Acta Otolaryngol* 4:283-288, 1955
9. Guilder RP, Hopkins LA: Auditory function studies in an unselected group of pupils at the Clark School for the Deaf. III. Relationship between hearing acuity and vestibular function. *Laryngoscope* 46:190-197, 1936
10. Rapin I: Consequences of congenital hearing loss: A long term view. *J Otolaryngol* 7:473-483, 1978
11. Rapin I: Hypoactive labyrinths and motor development. *Clin Pediatr (Phila)* 13:922-937, 1974
12. Rosenblut B, Goldstein R, Landau WM: Vestibular responses of some deaf and aphasic children. *Ann Otol Rhinol Laryngol* 69:747-755, 1960
13. Ayres AJ: Southern California Postrotary Nystagmus Test Manual. Los Angeles, CA, Western Psychological Services, 1976, pp 1-8
14. Kimball J: Normative comparison of the Southern California Postrotary Nystagmus Test: Los Angeles vs Syracuse data. *Am J Occup Ther* 35:21-25, 1981
15. Ayres AJ: Southern California Sensory Integration Tests Manual. Los Angeles, CA, Western Psychological Services, 1976, pp 50-54
16. Wilson VJ, Peterson BW: The role of the vestibular system in posture and movement. In Mountcastle VB (ed): *Medical Physiology*, ed 14. St. Louis, MO, CV Mosby Co, 1980, vol 1, pp 813-836
17. Hardy WG: Problems in diagnosis and management of the multiply-handicapped deaf child. *Arch Otolaryngol* 98:269-274, 1973
18. Effgen S: Effect of an exercise program on the static balance of deaf children. *Phys Ther* 61:873-877, 1981
19. Leiter RG: Leiter International Performance Scale. Chicago, IL, CH Stoelting Company, 1948
20. Wechsler D: Wechsler Intelligence Scale for Children—Revised. New York, NY, The Psychological Corporation, 1974
21. Stutsman R: Merrill-Palmer Scale of Mental Tests. Chicago, IL, CH Stoelting Company, 1931
22. Black FO, Wall C, O'Leary DP: Computerized screening of the human vestibulospinal system. *Ann Otol Rhinol Laryngol* 87:853-859, 1978
23. Morrison D, Sublett J: Reliability of the Southern California Postrotary Nystagmus Test with learning disabled children. *Am J Occup Ther* 37:694-698, 1983