Motor Proficiency Associated with Vestibular Deficits in Children with Hearing Impairments

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The purpose of this study was to investigate the relationship of vestibular function to motor proficiency, including balance, in children with hearing impairments. Thirteen children with normal hearing and 29 children with hearing impairments, ranging in age from 7 to 13 years, were classified into categories based on vestibular function using neuro-otologic measures (ie, vestibulo-ocular reflex function and posturography). Children in each category were tested for motor proficiency using clinical assessment measures (eg, balance, muscle tone, and coordination). The test results indicated that the children with hearing impairments and normal peripheral vestibular function (n = 7) exhibited normal motor proficiency, including balance. The children with hearing impairments and loss of peripheral vestibular sensitivity (n = 19) also demonstrated normal motor proficiency, except for balance ability. The children with hearing impairments and sensory organization deficits (n = 3), however, exhibited motor deficits in many areas. The results of this study indicate that motor proficiency in children with hearing impairments depends on vestibular function. Interventions for motor deficits in children with hearing impairments, therefore, must consider vestibular function as well as motor performance.

Key Words: *Hearing disorders; Motor skills; Pediatrics, evaluation; Vestibular function tests.*

It is well documented that the incidence of both vestibular and motor deficits is high in children with hearing impairments.[1–6] Most studies, however, do not compare motor proficiency in hearing-impaired children with and without well-defined vestibular deficits. Because the vestibular end organs and the cochlea are closely related in anatomy and development, strong potential exists for a related vestibular deficit when the hearing mechanism is impaired.

Rosenblut et al found that 49% of 107 children with deafness attributable to various etiological factors had depressed caloric-induced nystagmus.[2] Using both the Barany rotation test and caloric stimulation, Arnvig found that 82% of 89 children with severe postnatal hearing loss (eg, resulting from meningitis, measles, or encephalitis) and 34% of 129 children with inherited hearing loss had abnormal responses to vestibular tests.[4] Rapin urged that all children with hearing impairments undergo vestibular testing because of the high likelihood of delayed motor milestones.[6]

The literature also indicates that children with hearing impairments tend to display inferior balance and gross motor skills compared with children with normal hearing.[7–13] In contrast, children with hearing impairments often perform similarly to children without hearing impairments on fine motor coordination and visual-perceptual tasks, which are vital to manual communication methods.[7] Boyd found deficient balance and locomotor coordination in 90 deaf boys using an adaptation of the Oseretsky Scale.[8] Lindsey and O'Neal compared the performance of 31 8-year-old deaf children with that of 77 8-year-olds with normal hearing on a battery of 16 static and dynamic balance tests.[9] The deaf children failed significantly more balance tests than did the hearing group. Elimination of visual input in static balance tasks increased the difficulty of the tasks for both the deaf and hearing groups, with the deaf group more seriously impaired. Lindsey and O'Neal's study also showed that some children with hearing impairments performed as well as children with normal hearing in both static and dynamic balance tests.[9] Geddes concurred with this finding, showing that some 4- and 5-year-old children with hearing impairments functioned at their age level in total motor development.[10]

A few studies have investigated the relationship of tests of vestibular function to balance performance in children with hearing impairments,[11–13] but the tests of vestibular function used in these studies were qualitative or indirect. Ingalls-Holderbaum et al found that two caloric response categories (normal and abnormal) were correlated with performance on certain balance tests from the Floor Ataxic Test Battery but not with the Heath Rail-Walking Test.[11] With an assumption that the Fukada stepping-in-place test was sensitive for detecting vestibular impairments, Scanlon and Goetzinger found no correlation between the Fukada stepping-in-place test and locomotor ability as tested by the Heath Rail-Walking

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Test with a sample of 101 deaf subjects.[12] Potter and Silverman found, in 34 children with sensorineural deafness (aged 5–9 years), that the Southern California Postrotary Nystagmus Test (SCPNT) was not significantly related to the standing balance subtests of the Southern California Sensory Integration Tests (SCSITs).[13] Potter and Silverman concluded that the level of vestibular response was not significantly related to static standing balance.[13]

The contribution of the vestibular system to motor proficiency and balance is not well understood, although it is often assumed to be essential.[14,15] Parker emphasized, nevertheless, that "the vestibular system is only one source of information for a system of balance and orientation that is multimodal: the system also receives input from the eyes and somatic receptors."[16(p118)]

The purpose of this study was to investigate the relationship of vestibular function to motor proficiency, including balance, in children with hearing impairments. Children without hearing impairments were used as a control group to normalize neuro-otologic measures of vestibular function and to compare outcomes on clinical tests of motor proficiency. We expected that children with hearing impairments who demonstrated vestibular deficits as tested by neuro-otologic measures would exhibit decreased balance and motor proficiency. Quantitative neuro-otologic tests of both vestibulo-ocular reflexes and posturography allowed comparison of balance and motor proficiency among children with various types of vestibular dysfunction.

METHOD

Subjects

The subjects were 42 children ranging in age from 7 to 13 years. Thirteen Caucasian children (8 male, 5 female; $\bar{X}$ age = 8.9 years) with normal hearing were recruited from siblings of children with hearing impairments or children of employees of Good Samaritan Hospital and Medical Center in Portland, Ore, and served as control subjects. The control group was a sample based on convenience and was not matched with the subjects who had hearing impairments. The control subjects had no known neurological, psychological, motor, or academic problems based on parent report.

Twenty-nine children (11 male, 18 female; $\bar{X}$ age = 9.8 years) with hearing impairments were selected from the Regional Program for the Deaf to participate in the study. The subjects' hearing thresholds were higher than 30 dB in both ears. All hearing-impaired subjects attended public schools and had no known physical handicaps except their hearing impairments. None of the children were being treated by physical therapists or occupational therapists for sensorimotor disabilities. All of the children were of normal intelligence and had suffered their hearing loss within the first two years of life. Nine children were hearing-impaired as a result of meningitis, 1 child had rubella, 4 children had congenital hearing impairments, and the etiological condition was unknown in 15 children. Before the study began, parents and subjects signed informed consent statements approved by the Good Samaritan Hospital and Medical Center Human Subjects Committee. An interpreter attended all test procedures for children with hearing impairments who were not competent in lipreading.

Research Design

All subjects were classified according to their functional vestibular status using two quantitative neuro-otologic tests: 1) vestibulo-ocular reflex (VOR) function at two different rotation frequencies and 2) posturography (measurement of postural sway) under six different sensory conditions. Details of the testing procedures and of the distribution of neuro-otologic results in the subjects were described previously.[17] The motor proficiency of subjects in each vestibular classification was compared using a battery of 14 clinical assessments.

Different examiners were used for each phase of testing (VOR function, posturography, and clinical assessment). All examiners were blinded to the results of the other assessments. The clinical tests were administered by a pediatric occupational therapist (T.K.C.) who was certified to administer the SCSITs and who had extensive experience in the measurement of balance and motor proficiency in children.

Procedure

Neuro-otologic tests. We tested subjects' VOR function in complete darkness with the subject seated on a rotating chair and the head fixed at 30 degrees of flexion. A microcomputer-controlled turntable with chair was programmed to deliver horizontal sinusoidal rotation at 0.2 and 0.05 Hz. Various quantifiable characteristics of slow-phase eye movement velocity were calculated from the electronystagmography. Each subject's performance was compared with group mean data collected on 54 children with normal hearing, aged 7 to 12 years, including the 13 control subjects in this study. Loss of vestibular sensitivity was subclassified as bilaterally absent, bilaterally reduced, or asymmetrically reduced based on standard measures of VOR gain, phase, and asymmetry outside the .01 or .05 confidence level of the control subjects' data.[17]

Posturography was used to differentiate loss of peripheral vestibular sensitivity from sensory organization deficits in postural orientation using the equipment and procedure described previously.[18] Anteroposterior body sway was measured for 30 seconds under six sensory conditions in which somatosensory or visual inputs were altered. Somatosensory inputs provided orientationally inaccurate information (sensory conflict) when the support surface was rotated about the ankle axis in proportion to body sway.[19] Visual inputs were either removed by applying blindfolds or were made inaccurate (sensory conflict) by rotating a three-sided visual surround in proportion to body sway during testing.[19] Postural sway in excess of two standard deviations from the mean performance of 54 children with normal hearing (aged 7–12 years) in any of six sensory conditions was considered abnormal.[17] Loss of vestibular inputs (vertical canals and otoliths) for orientation was identified by excessive sway or falling when both somatosensory and visual inputs were missing or inaccurate, such that only vestibular inputs could provide orientation information.[18] Sensory organization deficits were identified by excessive postural sway or falling in sensory-conflict conditions.

Children with normal VOR function and normal postural sway in all six sensory conditions were classified as having normal vestibular function. Children with both abnormal VOR function (absent, bilaterally reduced, or asymmetrically reduced) and excessive sway in posturography conditions in which only vestibular inputs provided accurate inputs were classified as having a loss of vestibular sensitivity. Children with normal VOR function and excessive sway in posturography conditions of sensory conflict were classified as having

TABLE 1
Classification Based on Neuro-otologic Measures

Classification	Total
Normal hearing—normal vestibular function (control)	13
Hearing impaired—normal vestibular function	7
Hearing impaired—abnormal vestibular function	22
Loss of vestibular sensitivity	19
Absent	4
Bilaterally reduced	2
Asymmetrically reduced	13
Sensory organization deficit	3

sensory organization deficits. All 42 subjects in this study were classified with these criteria.

Table 1 summarizes the distribution of children into three main groups based on VOR function and posturography tests: 1) normal hearing with normal vestibular function (n = 13), 2) hearing impaired with normal vestibular function (n = 7), and 3) hearing impaired with abnormal vestibular function (n = 22). The 22 hearing-impaired subjects with abnormal vestibular function were further subclassified into subjects with loss of vestibular sensitivity (n = 19) and subjects with sensory organization deficits (n = 3).

Clinical tests. The battery of 14 clinical tests administered to all subjects consisted of:

1. Prone extension (PE) duration and quality.[20] The number of seconds the subject held a PE position was timed. Prone extension performance was evaluated with a five-point scale (0 = 0 seconds, 1 = 1–5 seconds, 2 = 6–10 seconds, 3 = 11–15 seconds, 4 = 16–20 seconds, and 5 = >20 seconds). Harris's qualitative rating scale was used to determine the quality of the PE posture.[21]

2,3. Standing balance-eyes open (SBEO); standing balance-eyes closed (SBEC). These subtests were administered as described in the SCSIT Manual.[22] Duration of standing balance on the left foot and right foot were combined for a total score.

4. Southern California Postrotary Nystagmus Test.[23] The SCPNT was administered according to the test manual instructions, with the addition of the following test controls: 1) a clean white sheet was placed on the wall and under the rotating board to decrease visual stimuli, 2) the rotating board was placed 18 in* from the wall, 3) an angle guide was used when flexing the child's head forward 30 degrees, and 4) the tester counted rotations of the board out loud to maintain the mental alertness of each child during testing.

5,6. Tilt board-eyes open (TBEO); tilt board-eyes closed (TBEC). Children stood on a tilt board with an angle guide placed behind the tilt board. The maximum number of degrees the tilt board could be moved before the child's foot left the board, hand(s) left the waist, or the child required assistance to maintain an upright position was recorded. For TBEC, degrees of tilt were recorded when the child either opened his eyes or made the above-described postural adjustments. The maximum degrees of tilt were summed for four directions of tilt (right, left, forward, and backward) for TBEO and TBEC.

7. Muscle tone. Muscle tone was measured according to Ayres's clinical observations of the upper extremities by examining the subject's relative amount of elbow hyperextension.[20] Muscle tone was evaluated on a three-point scale (1 = definitely hypotonic, 2 = slightly hypotonic, and 3 = normal). A score of 1 or 2 was considered deviant.

8. Extensibility. Examination of extensibility (ie, the amount of resistance felt during lower extremity range of motion) was adapted from the Movement Assessment of Infants manual.[24] Passive ROM in the lower extremities was scored on a range of 1 (no resistance) to 5 (strong resistance). All scores except 3 were considered deviant.

9. Rapid forearm rotation. Rapid forearm rotation was evaluated according to Ayres's clinical observations.[20] Performance was rated as 1 (definitely poor), 2 (slightly irregular), or 3 (normal). For analysis, the performances of the right arm, left arm, and both arms were combined for the forearm rotation and opposition measures.

10. Opposition. Opposition (thumb-finger touching) was also rated according to Ayres's clinical observations[20] using the same scoring method as the rapid forearm rotation test.

11. Skipping. The child was asked to skip 25 ft† and was then rated using a three-point scale (1 = definitely irregular, 2 = slightly irregular, and 3 = normal).

12. Scoliosis. Visual observation of the level of superior aspects of the child's shoulders and the lower borders of the scapuli were made. The child then flexed at the waist, and visual comparison was made of the contour of the back. The scoliosis clinical observation was scored as 1 (definite scoliosis), 2 (questionable scoliosis), or 3 (normal back curvature).

13. Bruininks-Oseretsky Test of Motor Proficiency (BOTMP).[25] The balance, bilateral coordination, strength, and running speed and agility subtest standard scores were obtained.

14. Vestibular summary clinical impression. Finally, based on the information collected from all of the clinical tests, the therapist (T.K.C.) evaluated the overall vestibular status of each subject. Subjects were given a 0 if they did not have a vestibular deficit and a 1 if they had a vestibular deficit.

Data Analysis

Based on previous literature,[26,27] the first six clinical measures (PE duration, SBEO, SBEC, SCPNT, TBEO, and TBEC) were considered to be most related to vestibular function. Performance on these measures was compared between the control subjects and the hearing-impaired subjects with abnormal vestibular function using *t* tests. Visual inspection of the data and initial analyses using the Kolmogorov-Smirnov two-sample test indicated that the distributions of the six variables met the assumption of normality.

The six PE quality test results were examined with a chi-square analysis. A Fisher's exact test verified no difference ($p < .3$) in quality measurements between the control subjects and the hearing-impaired subjects with normal vestibular function. We used a chi-square test to compare PE quality measurements between the 22 hearing-impaired subjects with abnormal vestibular function and the 20 subjects with normal

*1 in = 2.54 cm.

†1 ft = 0.0348 m.

vestibular function (7 hearing-impaired subjects and 13 control function subjects).

The remaining six nonstandardized clinical measures (Ayres's muscle tone, extensibility, rapid forearm rotation, opposition, skipping, and scoliosis) were examined descriptively as percentages of children with deviant scores in each of the three main groups (normal hearing with normal vestibular function, hearing impaired with normal vestibular function, and hearing impaired with abnormal vestibular function). Standardized, age-normed scores were used to analyze subjects' performance on the BOTMP subtests. The classification of subjects into normal and abnormal vestibular function based on the clinical impressions of the therapist administering the clinical tests of motor proficiency was compared with the normal and abnormal classifications of vestibular function based on neuro-otologic tests.

RESULTS

The 7 hearing-impaired children with normal vestibular function scored very similarly to the 13 children with normal hearing and normal vestibular function on the six clinical measures of motor proficiency (Tab. 2): 3.7 points on PE duration, 113.0 seconds on SBEO, 14.0 seconds on SCPNT, 36.4 degrees on TBEO, and 31.4 degrees on TBEC. The hearing-impaired subjects with abnormal vestibular function had significantly lower scores than the control subjects on one-foot SBEO and SBEC and 2 on the SCPNT (Tab. 2). No significant differences were found between the two groups on PE duration, TBEO, or TBEC. No difference existed in the proportion of subjects in the two groups who scored poorly on the six measures of PE quality ($p > .10$). We noted, however, that extremely poor performance (ie, requiring considerable exertion and thighs totally on the mat) was never observed in the control subjects but was occasionally seen (5/22 and 3/22) in the hearing-impaired subjects with abnormal vestibular function.

The subgroup of four hearing-impaired subjects with completely absent vestibular function had mean scores of less than half of the scores achieved by the total group of hearing-impaired children with abnormal vestibular function on four of the six clinical measures in Table 2. The two exceptions were PE duration, which was maintained even longer than for the control subjects, and TBEC, which was not very different among groups. The mean performance scores of the hearing-impaired subjects with absent vestibular function were 5 points (>20 seconds) on PE duration, 9.5 seconds on SBEO, 2.75 seconds on SBEC, 0 seconds on the SCPNT, 16.8 degrees on TBEO, and 16.4 degrees on TBEC.

The subgroup of three hearing-impaired subjects with sensory organization deficits performed near the mean of the total group of hearing-impaired children with abnormal vestibular function on all measures except SBEO, which was less than half the mean score (Tab. 2). Their mean scores were 3.7 points on PE duration, 13 seconds on SBEO, 6 seconds on SBEC, 5.3 seconds on the SCPNT, 30.3 degrees on TBEO, and 21.8 degrees on TBEC.

In the six nonstandardized clinical measures (numbers 7–12), the three main subject groups performed with varying degrees of motor proficiency. No consistent relationship existed between hearing impairment or vestibular status and the percentage of children in each group with deviant scores for these measures (Fig. 1).

Figure 2 displays the individual performance of subjects in the three main groups and the two subgroups on the four gross motor subtests of the standardized BOTMP. The hearing-impaired children with normal vestibular function scored within two standard deviations of the standard mean on all four subtests, and control subjects scored above the published standard means in bilateral coordination, strength, and running speed and agility. Performance scores varied for the hearing-impaired subjects with vestibular deficits for bilateral coordination, strength, and running speed and agility, but all children with vestibular deficits scored below the published mean standard score of 15 in balance. Hearing-impaired subjects with bilaterally absent vestibular dysfunction tended to score in the midrange on all motor proficiency subtests except for the balance subtest, in which they scored more than two standard deviations below the standard mean. In contrast, subjects with sensory organization deficits tended to score at the bottom of the range on all four motor proficiency subtests.

The overall clinical impression of vestibular function gathered by this study's clinical protocol allowed the testing ther-

TABLE 2
Subjects' Scores on Six Clinical Measures of Motor Proficiency

Test	Subjects: Normal Hearing with Normal Vestibular Function (n = 13)			Subjects: Hearing Impaired with Abnormal Vestibular Function (n = 22)			p
	$\bar{X}$	s	Low-High Score	$\bar{X}$	s	Low-High Score	
Prone extension duration (5-point scale)	4.5	0.9	3–5	4.0	1.4	1–5	.194
One-foot standing balance—eyes open R and L (sec)	137.8	113.0	24–360	34.6	28.4	7–95	.004[a]
One-foot standing balance—eyes closed R and L (sec)	15.1	12.3	5–50	5.5	2.7	2–11	.018[b]
Southern California Postrotary Nystagmus Test (sec)	14.2	8.1	0–28	6.2	7.6	0–25	.006[a]
Tilt board—eyes open (°)	32.1	4.9	5–45	33.6	4.8	10–45	.397
Tilt board—eyes closed (°)	25.8	8.5	5–45	19.1	11.0	0–40	.070

[a] $p < .01$.
[b] $p < .05$.

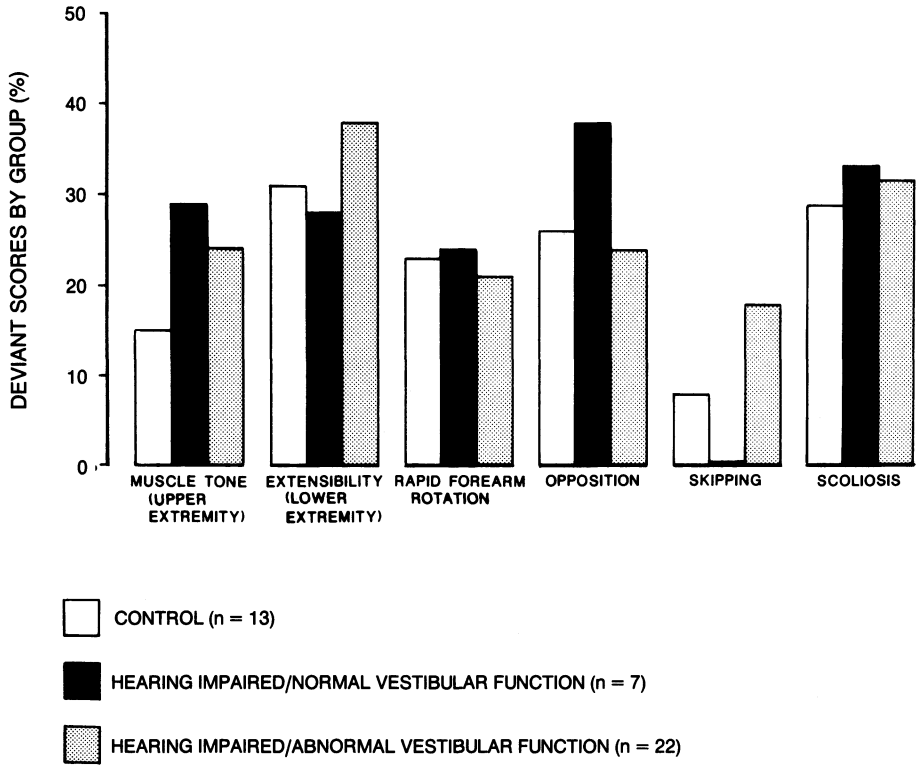

Fig. 1. Percentage of subjects with deviant scores on six nonstandardized clinical measures of motor proficiency by group.

apist to make accurate clinical judgments regarding normal or abnormal vestibular function classification of the 13 children with normal hearing and the 29 children with hearing impairment.

DISCUSSION

Hearing-impaired Subjects with Normal Vestibular Function

The seven hearing-impaired subjects with normal vestibular function (based on quantitative neuro-otologic VOR function and posturography tests) performed similarly to the control subjects in all clinical measures of balance and motor proficiency. This minority group of subjects with hearing impairments seemed to have normal postural responses, balance, muscle tone, bilateral coordination, and strength. They even performed slightly better than the control subjects on measures of tilt-board stability, extensibility, and skipping. These results concur with the findings of Lindsey and O'Neal[9] and Geddes,[10] who reported that a subgroup of children with hearing impairments had age-expected motor proficiency.

Hearing-impaired Subjects with Abnormal Vestibular Function

Children with hearing impairments are often labeled as clumsy or uncoordinated, but the results of this study indicate that only children with abnormal vestibular function have problems with motor proficiency. In addition, the motor proficiency of children in this study with loss of vestibular sensitivity, as indicated by abnormal VOR function and excessive postural sway only when both somatosensory and visual inputs were missing, differed from the motor proficiency of children with sensory organization deficits, as indicated by normal VOR function and excessive postural sway in any sensory conflict situation. Children with loss of vestibular sensitivity that occurred early in life scored below average only in balance tests, whereas those with sensory organization deficits scored below average on many tests of motor proficiency, including balance.

The hearing-impaired subjects with loss of vestibular sensitivity performed similarly to the control subjects in measures of bilateral coordination, strength, and running speed and agility, despite their marked difficulty in balance tasks (SBEO, SBEC, and BOTMP balance subtest). Clinical measures of muscle tone, extensibility, rapid forearm rotation, skipping, scoliosis, and PE duration were also similar to the performance of the control subjects. When peripheral vestibular sensitivity is reduced or absent in children, the resulting problems in motor proficiency appear to be discrete. Overall, children with loss of vestibular sensitivity appear to be functionally capable in their interactions with the environment except in certain balance activities.

Subjects with abnormal vestibular function tended to fall with fewer degrees of tilt on the TBEC. The TBEC test was limited by the accuracy of measuring degrees of tilt-board movement at the time of disequilibrium. It is unclear, however, whether a significant difference would have been obtained with a more accurate measure of tilt or whether subjects with vestibular function deficits were able to rely on surface cues from the slowly tilted board during TBEC.

In addition to poor balance, subjects with abnormal vestibular function, based on otologic measures of VOR function and posturography, also had shorter mean total duration scores on the SCPNT (Tab. 2). The large standard deviation for this group, however, indicated that, although many of these children had shortened postrotatory nystagmus, some subjects had normal responses, and a few subjects had prolonged responses. The SCPNT identified the four children

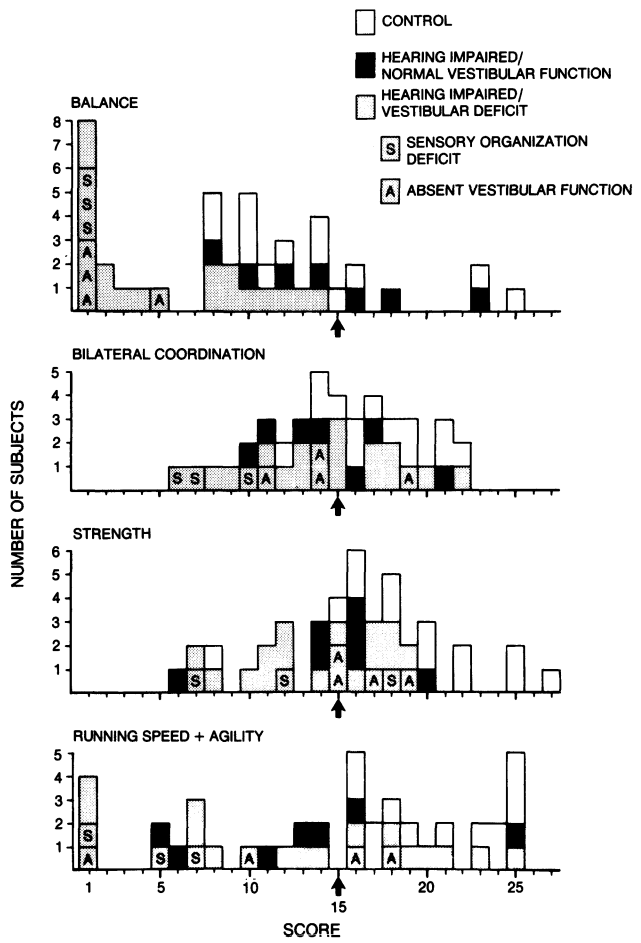

Fig. 2. Subjects' standard scores on the four gross motor subtests of the Bruininks-Oseretsky Test of Motor Proficiency (mean standard score of each subtest = 15).

with absent VOR function responses by the observation of zero nystagmus following rotation both to the right and left on the SCPNT. Guilder and Hopkins, using an undefined method to measure postrotatory nystagmus, also found a shorter mean duration of postrotatory nystagmus in an unclassified group of 100 deaf children.[5]

Hearing-impaired Subjects with Sensory Organization Deficits

The three hearing-impaired subjects with sensory organization deficits performed poorly on all motor proficiency measures. Their poor performance in tasks requiring bilateral coordination, strength, and running speed and agility; their postural instability when surface or visual inputs were inaccurate (sensory conflicts); and their normal VOR function matched the performance of hearing children with learning disabilities who were referred for motor coordination problems.[17,28] Despite normal horizontal VORs, the three subjects with sensory organization deficits had abnormally short postrotatory nystagmus as tested by the SCPNT. Because no measure of otolith or vertical canal function exists, we could not determine whether the pathological condition leading to a sensory organization deficit was due to a central or peripheral nervous system problem. Peripheral vestibular pathological conditions (eg, perilymph fistulas and benign paroxysmal positional nystagmus) can affect primarily otolith and vertical canal function and thus be associated with normal horizontal VORs.[14,17,18,30] Rather than causing loss of vestibular sensitivity, irritative lesions can result in distorted, inaccurate vestibular information.[18,32] If the damage is within the CNS (ie, the vestibular nucleus or brain stem), postrotatory nystagmus may be abnormal, despite a normal peripheral afferent system and possibly a normal horizontal VOR gain and phase.[14,15]

Clinical Tests of Abnormal Vestibular Function

The most discriminating clinical tests for vestibular dysfunction in this study were 1) one-foot SBEO; 2) the BOTMF balance subtest, which includes standing and walking on both a line and a beam and one-foot standing; and 3) SCPNT duration. A larger difference existed between the groups with normal and abnormal vestibular function on the measure of SBEO than on SBEC. This result is surprising, because elimination of vision reduces the number of redundant sensory inputs for orientation. One reason why the SBEO condition may be more discriminating than the SBEC condition was that subjects with normal vestibular function could maintain the one-foot standing position with eyes closed for only a short period of time. In this respect, our results agree with those of Stones and Kozoma, who, in a study of balance deficits in the aged, found SBEO to be a more reliable and sensitive index of postural control capability than SBEC.[29]

Certain balance tests may be sensitive indicators of peripheral vestibular loss because 1) they place individuals in environments without redundant visual and surface sensory inputs or 2) they require a movement pattern in which vestibular input is critical. Recent studies have demonstrated that children and adults with absent peripheral vestibular function do not adjust body center of mass using hip movements when ankle torque is limited by standing across a narrow beam.[30] The most sensitive equilibrium positions to test for loss of vestibular sensitivity, therefore, may be found in tests such as the BOTMP balance subtest that require hip postural movements to stand or walk on a balance beam or a line or to stand on one foot.

Several clinical measures frequently used to screen for vestibular and other sensorimotor deficits did not identify the subjects in this study with vestibular deficits. These measures include Ayres's muscle tone, extensibility, PE duration and quality, forearm rotation, opposition, and skipping. This finding contrasts with that of Ottenbacher, who found that PE duration and Ayres's muscle tone were related to postrotatory nystagmus duration on the SCPNT in children with learning disabilities.[26]

Subjects in this study with otologically identified vestibular deficits tended to have reduced duration of postrotatory nystagmus, but caution should be exercised when drawing conclusions from the results of this study regarding vestibular status from clinical measures of postrotatory nystagmus. Postrotatory nystagmus duration is a measure of both vestibularly driven eye movements and the central integrator responsible for nystagmus long after the stimulus has ended.[31]

Despite the danger of relying on any single clinical measure for indication of vestibular pathology, the results of this study indicate that certain clinical tests may be more discriminating than others in detecting vestibular deficits. The results of this

study also indicate that therapists using overall clinical judgment scores of vestibular status may be able to discriminate between hearing-impaired children with vestibular deficits and hearing-impaired children without vestibular deficits. The two subclassifications of vestibular dysfunction (absent vestibular function and sensory organization deficits) could be differentiated by absence of postrotatory nystagmus and deficiencies in motor proficiency tasks other than balance, respectively. Because of the high incidence of vestibular dysfunction associated with hearing dysfunction, children with hearing impairments and poor balance proficiency should be referred for neuro-otologic testing. Further studies analyzing the specificity and sensitivity of clinical measures of vestibular function compared with otologic measures are needed.

Rehabilitation Implications

Difference in motor performance between the subjects with loss of vestibular sensitivity and those with sensory organization deficits suggest that very different therapeutic approaches should be used for their rehabilitation. Hearing-impaired children with loss of vestibular sensitivity may benefit from a program specifically designed to address balance strategies in various environmental contexts. This training will help them compensate for absent vestibular function by relying on their visual and somatic senses. Effgen reported a significant difference in standing balance duration between an experimental group of hearing-impaired children who participated in a 10-day exercise program of static balance activities and an untreated hearing-impaired control group.[33] Hearing-impaired children with sensory organization deficits, however, would probably benefit from a global intervention program designed to address problems such as deficits in bilateral coordination and inability to resolve sensory conflict situations.

CONCLUSIONS

The results of this study indicate that 1) hearing-impaired children with normal peripheral vestibular function are not impaired in motor proficiency, including balance; 2) hearing-impaired children with abnormal peripheral vestibular function demonstrate normal motor proficiency except for balance ability; 3) hearing-impaired children with sensory organization deficits have poor motor proficiency in many areas, including balance; and 4) therapists can use clinical tests to discriminate between different types of vestibular function in hearing-impaired children to design appropriate intervention programs for improving motor proficiency.

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