International Journal of Pediatric Otorhinolaryngology (2004) **68**, 1141—1148

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International Journal of Pediatric Otorhinolaryngology

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Improvement of motor development and postural control following intervention in children with sensorineural hearing loss and vestibular impairment[☆]

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Received 4 October 2003; received in revised form 28 March 2004; accepted 2 April 2004

KEYWORDS
Vestibular rehabilitation;
Children;
Substitution;
Developmental delay;
Sensory integration

Summary ***Objective:*** The purpose of this study was to determine the effect of exercise intervention on the progressive motor development delay and postural control impairments in children with sensorineural hearing loss and concurrent vestibular impairment. ***Methods:*** Twenty-one children with sensorineural hearing loss and vestibular impairment were randomly assigned to two groups (exercise and placebo) matched for age and gross motor development level. Exercise intervention consisted of compensatory training, emphasizing enhancement of visual and somatosensory function, and balance training. Placebo intervention focused on language development activities. Each intervention was administered three times weekly for 12 weeks. Motor development and posturography testing was completed pre- and post-intervention. To examine the mechanisms of change, somatosensory, visual and vestibular functional effectiveness ratios were calculated from posturography stability scores. Children in the placebo group later participated in exercise intervention, and a second post-test completed. Data were analyzed by group, as well as merged once all had received exercise intervention. ***Results:*** Post-intervention, motor development scores significantly improved in the exercise, not the placebo group ($P = 0.004$). Although not significant, improvement in posturography scores were evident in the exercise group. Once the post-exercise data from both groups were merged ($n = 21$), improvements in these scores were significant (≤ 0.02). The difference from the normative sample was eliminated. ***Conclusions:*** Exercise intervention focused on the enhancement of sensory integrative postural control abilities is effective for the arrest of the progressive motor development delay in children with sensorineural hearing loss and vestibular impairment.

[☆] This study was supported by a research grant from the Foundation for Physical Therapy and NICHD #HD37820-02.

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doi:10.1016/j.ijporl.2004.04.007

1. Introduction

Hearing loss is usually diagnosed early in life. Although early intervention focused on the development of communication skills is initiated, the motor development delays that have been reported in this population [1—3]are not typically addressed. Rine et al. [1] reported that children with sensorineural hearing impairment (SNHI), as opposed to a conductive loss, have progressive developmental motor deficits. Furthermore, it has been postulated that these deficits are related to concomitant damage to vestibular structures [1,3—5]. Reportedly [3,4,6], children with hearing impairment and concurrent vestibular dysfunction have deficits in sensory organization as measured by posturography sensory conditions testing (SCT). These reports, and reports that the critical period of postural control development is between 4 and 6 years of age [7,8] suggest that intervention to address the motor deficits in this population should be provided before this age. Despite this, and reports of the efficacy of intervention for adults with vestibular dysfunction [9—11], similar reports of intervention for children are not available.

Research has shown that adults with vestibular dysfunction benefit from physical therapy rehabilitation [10—12]. Krebs et al. [11] reported significant improvement of motor skills in adults with bilateral vestibular hypofunction following eight weeks of vestibular, not sham, treatment. The vestibular program was based on comprehensive evaluation of vestibular function and posturography which identified diminished stability scores on test conditions relying on visual and somatosensory information to resolve sensory conflict. Patients who participated in the vestibular program, which included visual training with and without head movement, gait with varying base of support size and surface compliance, and goal oriented movement tasks, had improvement of motor ability and scores on these posturography tests. These results suggest that improved visual and somatosensory effectiveness in postural control contributed to the improved motor abilities [11]. Similar testing and examination of the effectiveness of intervention in children has not been done.

Rine et al. [1] reported a progressive motor development delay and deficient postural control which was related to concurrent vestibular dysfunction in young children with SNHI. Rine et al. [6] reported postural control sensory organization deficits in this population. Posturography testing, which provides indirect functional measurement of the contribution of the sensory systems involved in postural control, was completed on children with SNHI and vestibular impairment and typically developing peers. The children with SNHI achieved abnormally low scores on all sensory effectiveness ratios ($P \leq 0.05$). These results support the idea that children with SNHI and a concurrent vestibular deficit have a sensory organization deficit that warrants intervention.

Investigations of intervention for the amelioration of balance deficits in children with hearing loss have been minimal and inconclusive. Effgen [13] studied the effects of single leg stance practice on postural sway measures in 7—11-year-old children with hearing impairment and found no improvement. Lewis et al. [14] reported that participation in a balance and body awareness program did result in improved balance skills in 6—8-year-old children with hearing impairment. However, vestibular function and postural control mechanisms were not tested, and the intervention was not focused on facilitation of adaptation and substitution, which has been shown to be efficacious for the improvement of function in adults with vestibular impairments. The purpose of this study was to determine the effect of exercise intervention on motor development and sensory effectiveness in postural control in young children with SNHI and vestibular impairment.

2. Method

A placebo—controlled wait-listed design was used with subjects participating in a 12 week program of exercise or placebo intervention. The children initially participating in placebo intervention were provided the exercise intervention following the post-test, and a second post-test was administered. Examiners completing postural control and motor development testing were blinded as to group placement.

2.1. Subjects

Twenty-five children three through 8.5 years of age were recruited from the University of Miami—Dade County Public School Program for the Deaf and Hard of Hearing. Informed consent was obtained from the parents of all participants, and assent obtained from all subjects 7 years of age and older, as per the protocol approved by the University of Miami School of Medicine, Institutional Review Board. Only data from those with bilateral vestibular impairment, as per Rotary chair testing ($n = 21$), were analyzed.

Children with bilateral vestibular impairment were assigned to either the exercise ($n = 10$) or placebo ($n = 11$) group using a random-block design. Groups were matched for age and age equivalent score on motor development testing. Exclusion criteria were any cognitive, physical, visual or neurological condition (other than SNHI and vestibular impairment). This was confirmed by review of educational and medical records, and examination by a physical therapist. This examination included screening of range of motion, strength, neurological status and vision. Because visual stimuli was an important component of the intervention, visual deficits were ruled out via vision testing by a nurse practitioner using the MTI Photoscreener, which has been shown to provide reliable and valid measures in young children [15].

2.2. Instrumentation

Subject demographics were obtained by review of educational records. Vestibular function testing was completed pre-intervention. Motor development and postural control testing was completed pre- and post-intervention.

Rotary chair (sinusoidal harmonic acceleration and trapezoidal) testing of the VOR was completed on all subjects with SNHI. The sinusoidal test determined the gain, phase and asymmetry of the VOR during various accelerations. Six test frequencies were examined (0.01, 0.02, 0.04, 0.08, 0.16, and 0.32 Hz) at 50°/s over three to nine cycles. Trapezoidal testing was done using a series of complete chair rotations to both the right and left (100°/s for 60 s). Electrooculography was used to indirectly record eye movements through placement of electrodes on the lateral canthus of each eye, above and below the superior and inferior lids, and on the forehead (ground). The Rotary chair was contained within a closed sphere and had a computer-controlled motor. Children were seated in the lap of an adult, and the head was gently immobilized and pitched forward (30°) in the plane of the horizontal semicircular canal. An infrared camera within the sphere allowed monitoring of correct head position. Calibration was done prior to testing by having the subject look center, left and right 10° (three repetitions) at a red illuminated dot. Calibration, as well as all testing, was performed in total darkness and a two-way radio was used for constant communication between the adult with the child and the examiner regarding eye position and alertness. The results were compared to published age-matched normative data [16] and scored: (1) normal: within 1.5 standard deviations of the comparative sample mean; (2) bilateral vestibular impairment: gain values >1.5 standard deviations from the normative mean; and (3) unilateral loss: abnormal phase and asymmetry values in the presence of normal gain values. Only children with scores indicative of bilateral vestibular impairment participated in further testing and intervention.

Posturography sensory conditions testing (SCT) was performed using the SMART Balance Master System (NeuroCom International Inc.). This unit includes an enclosure and force platform that allows computerized measurement of postural stability used to maintain vertical orientation. The SCT yields measures of postural sway when the somatosensory and/or visual information regarding orientation of the body's center of gravity in relation to vertical is systematically manipulated [17—19]. This manipulation is sway-referenced (i.e. either the support surface or visual surround is rotated about the ankle joint axis in a 1:1 ratio to the subject's spontaneous anterio-posterior sway). Postural sway measures are obtained under six sensory conditions: (SCT-1) eyes open, fixed support; (SCT-2) eyes closed, fixed support; (SCT-3) sway-referenced vision, fixed support; (SCT-4) eyes open, sway-referenced support; (SCT-5) eyes closed, sway-referenced support; (SCT-6) sway-referenced vision, sway-referenced support. To more clearly delineate the effectiveness of the sensory modalities in postural control, and thus, examine sensory integrative abilities in young children, visual, somatosensory, and vestibular effectiveness ratios were calculated from the SCT stability scores (visual = SCT-4 stability/SCT-1 stability; somatosensory = SCT-3 stability/SCT-1 stability; vestibular ratio = SCT-5 stability/SCT-1 stability) [20,21]. Scores were compared to normative data collected in this lab and reported previously [20]. Because scores achieved by children in these age groups on SCT-6 are extremely low and of limited validity, this test condition was eliminated from the protocol. The same examiner completed all testing and was blinded to group placement.

Motor development was tested using the gross motor scale of the Peabody developmental motor scales (PDMS) [22], a norm referenced standardized test that yields standardized z and age equivalent scores for the scale as well as for each sub-test (i.e. reflex, balance, locomotor, non-locomotor, receipt, and propulsion of objects). To control for typical developmental progress and yet examine the effectiveness of intervention on motor development gain, baseline and intervention developmental quotients were calculated (age equivalent score/age in months, and change in age equivalent score/4 months, respectively). These scores are indicative of the rate of development. This method has been shown to be optimal in the examination of program effect on developmental gains [23]. The same investigators completed and scored all tests pre- and post-intervention and were blinded to group assignment. Good—excellent inter-rater reliability was established prior to actual testing (ICC(3,1) $= 0.91$), and all were blinded to group placement. Despite the upper age limit of 84 months and the expectation that three of the children would be 2—3 months beyond that age at the second test, this test was used, since tests appropriate for the older children (e.g. Bruininks—Oseretsky test of motor proficiency [24]) cannot be used for the younger children and do not differentiate balance skills in children less than 5 years.

3. Intervention

Exercise and placebo intervention was carried out by a research assistant (the same for both) under the direction of a physical therapist (exercise) or audiologist (placebo) for 12 weeks. Intervention consisted of 30 min sessions, three times per week, with make-up sessions provided for sessions missed due to illness or school vacation/holiday to assure that each child participated in a minimum of 30 sessions within the four month period. The exercise intervention was designed to enhance visual-motor and somatosensory abilities and thus enable substitution. Specifically, exercise sessions included 10 min of activities in three of four categories: eye hand coordination, general coordination activities, visual motor training, and balance training emphasizing visual and somatosensory awareness. The activities were similar to those described by Krebs et al. [11], and were modified based on age appropriate expectations of motor abilities, attention span and the motivational factors critical for the cooperation of children. Activities for each session were predetermined so that the time allotted to activities in each category were equivalent. Progress was charted weekly, reviewed biweekly by a physical therapist not involved in testing and, based on individual progress, the difficulty level was advanced. Placebo intervention consisted of three 30 min sessions per week of language development training.

4. Statistical analysis

A priori power analysis on preliminary data [25] revealed that a sample size of 25 was needed in each group for an effect size of 1.35 with sufficient power (0.80). Therefore, descriptive and frequency analysis was performed to examine trends in changes of pre- and post-intervention test scores. Descriptive statistics were performed to examine distributional properties of all variables and subject demographics. To examine gross motor development status pre-intervention, a *t*-test was used to compare scores achieved by the children participating and the normative scores provided with the PDMS. Because all children achieved a maximum score on the reflex sub-test, these scores were eliminated from further analysis. To examine the effect of intervention on motor development, general linear model analysis and paired *t*-test were completed on developmental quotients and raw scores, with subjects serving as their own control. Due to previous reports of age effect on SCT stability scores, and the non-normal distribution of this variable, non-parametric analysis was used to compare scores of children tested here to a normative sample ($n = 62$) by age group [20] and to examine the effect of intervention.

5. Results

Of the 25 children tested, 21 (84%) achieved scores indicative of bilateral vestibular impairment, and 4 (16%) achieved scores within the normative range on rotary chair testing. Grouping and further analysis was limited to those with vestibular impairment.

Descriptive analysis and *t*-test revealed that pre-intervention, the groups were similar in age, motor development, and SCT scores (Table 1). PDMS scores achieved pre-intervention were below published norms ($P \leq 0.001$), and thus, indicative of a significant motor development deficit. Postural control deficits were evidenced by scores significantly below that of the normative sample on SCT-3 ($P \leq 0.02$), and on the somatosensory and vision ratios ($P = 0.003$ and 0.05, respectively). Following exercise, no placebo intervention, motor development and postural control improved.

The PDMS raw scores achieved by the exercise group at post-test were significantly improved from those at pre-test ($P = 0.004$; Table 2), whereas those of the placebo group were unchanged. Although pre-test developmental quotients were similar between groups, the intervention quotient of the exercise group improved at post-test ($P = 0.04$; Table 2; Fig. 1) and was higher than those of the placebo group ($p = 0.005$). Interestingly, the intervention quotient achieved by the placebo group at this post-test was reduced from 0.78 to 0.55 (Fig. 1), which supports the concept that the developmental delay is progressive in these children. The placebo group participated in exercise intervention following this post-test, with significant

Table 1 Summary subject demographics at pre-test

	Group	
	Exercise ($n = 10$)	Placebo ($n = 11$)
Age (mean, in months)	67.54 (19)[a]	68.4 (17)[a]
Gender		
Male	3	6
Female	7	5
Race		
Caucasian	3	2
Hispanic	3	6
Black	3	3
Indian	1	0
Hearing level		
Bilateral profound	6	8
Bilateral severe	2	1
Severe/moderate[b]	2	1
Profound/moderate[b]	0	1
Etiology		
Premature	2	0
Cytomegalovirus	1	1
Heredity	3	2
Antibiotics	1	1
Kallman syndrome	0	1
Unknown	6	6
Motor development (mean)		
Age equivalent score (months)	52.6	52.3
Developmental quotient	0.83	0.78
Raw score	282 (19)[a]	287 (34)[a]

[a] Standard deviation provided in parentheses.
[b] Hearing level in each ear.

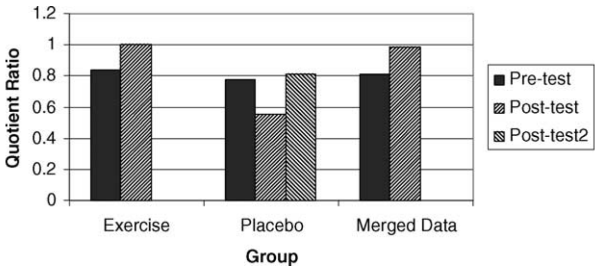

Fig. 1 Pre-exercise developmental and intervention quotients (post-test) for each group and pre-exercise and intervention merged data is provided. The second post-test data obtained on the placebo group are test results after participation in exercise intervention for this group only (post-test 2).

improvement in raw scores and intervention quotient at the second post-test ($P = 0.001$ and 0.05, respectively; Table 2; Fig. 1). These results suggest that participation in exercise intervention not only improved motor development status, but reversed the progressive nature of the motor development delay.

As noted above, prior to intervention the merged scores on SCT-3 and the vision and somatosensory ratios were below that of the normative sample (Table 4). Results of Wilcoxon signed rank tests revealed that the exercise, not placebo, group had improved stability scores on SCT-3 ($P = 0.03$; Table 3). Although improvement in vision and somatosensory ratio scores observed in the exercise group was not significant, scores achieved by this group no longer differed from the normative sample, indicating improvement (Figs. 2 and 3; Table 4). This improvement was not evident following placebo intervention (Table 4; Figs. 2 and 3). The placebo group participated in exercise intervention after this post-test, with similar improvements noted at the second post-test (Table 3; Figs. 2 and 3). When the post-exercise data was merged for all subjects ($n = 21$), improvement on SCT-3 and the somatosensory and vision ratio scores was significant ($P \leq 0.02$; Table 3). After exercise intervention, scores of the children with SNHI and concurrent vestibular impairment did not differ from the normative sample (Table 4; Figs. 2 and 3).

Table 2 Change in PDMS[a] scores between pre- and post-tests: results of paired *t*-test by group

	Raw scores			DQ[b]		
	Mean (S.D.)	*t*	*P*-value	Mean (S.D.)	*t*	*P*-value
Exercise group ($n = 10$	294 (22)	−3.6	0.004	1.0 (.21)	−3.4	0.04
Placebo group ($n = 11$)	290 (25)	−2.1	0.07	0.55 (.23)	0.62	0.38
Placebo group second post-test[c]	303 (22)	−3.4	0.001	0.81 (.23)	−3.9	0.05
Merged data[d]	299 (22)	−5.1	0.001	0.90 (.22)	−4.6	0.001

[a] Peabody devlopment motor scale.
[b] Comparison of pre-test developmental quotient to exercise intervention quotient.
[c] Scores achieved by this group after exercise intervention.
[d] Data from both groups combined after all had participated in exercise intervention.

Table 3 Comparison of pre- and post-test posturography scores: results of Wilcoxon signed rank test

	SCT-3[a]		Somatosensory ratio[b]		Vision ratio[c]	
	z	*P*-value	*z*	*P*-value	*z*	*P*-value
Exercise group ($n = 10$)	2.20	0.03	1.43	0.15	0.78	0.20
Placebo group ($n = 11$)	0.18	0.86	0.59	0.55	0.31	0.75
Second post-test[d]	−2.13	0.03	−1.2	0.10	−2.62	0.009
Merged data ($n = 21$)[e]	6.41	0.001	2.55	0.01	2.4	0.02

[a] Posturography sensory conditions test 3: sway-referenced visual surround.

[b] Ratio of stability scores: SCT-3/SCT-1.

[c] Ratio of stability scores: SCT-4/SCT-1.

[d] Change after second post-test, after exercise intervention for the placebo group.

[e] Scores from both groups combined: pre-test compared to scores after exercise intervention.

Table 4 Comparison of posturography scores to normative sample ($n = 62$): results of Mann–Whitney tests

	SCT-3[a]		Somatosensory[b]		Vision[c]	
	U	*P*-value	*U*	*P*-value	*U*	*P*-value
Merged data pre-test ($n = 21$)	57	0.02	282	0.003	68	0.05
Exercise ($n = 10$)	22	0.21	190	0.31	19	0.44
Placebo ($n = 11$)	11	0.01	225	0.09	98	0.01
Merged data ($n = 21$)[d]	27.5	0.40	194	0.26	20	0.40

[a] Stability score from posturography sensory conditions test 3: sway-referenced visual surround.

[b] Somatosensory effectiveness ratio: SCT-3 stability score/SCT-1 stability score.

[c] Vision effectiveness ratio: SCT-4 stability score/SCT-1 stability score.

[d] Data from both groups combined, after all received exercise intervention.

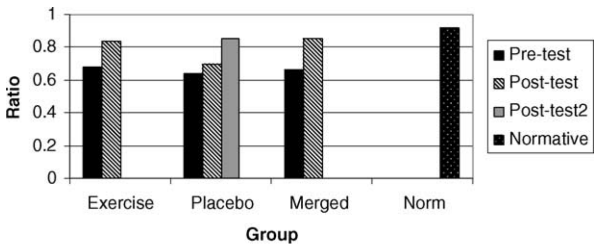

Fig. 2 Somatosensory ratio scores achieved pre- and post-intervention for each group and for pre- and post-exercise merged data is illustrated. Normative data is provided for comparison. Second post-test data from the placebo group are the data obtained after participation in exercise intervention for this group only.

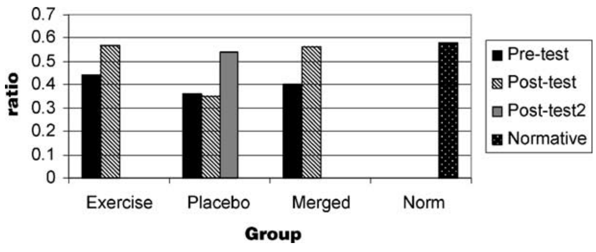

Fig. 3 Vision ratio scores achieved pre- and post-intervention is illustrated for each group (exercise and placebo) as well as with data merged (pre- and post-exercise). Normative score is provided for comparison. Second post-test data from the placebo group are the data obtained after participation in exercise intervention for this group only.

6. Discussion

Results suggest that for children with SNHI and concurrent vestibular impairment, participation in exercise intervention improved sensory organization for postural control and halted the progressive motor development delay. The identification of a sensory organization deficit at pre-intervention and the improvement in somatosensory and vision ratio scores following intervention suggests that this improvement contributed to the gain in motor development status.

Our results are contrary to previous reports [13], in which a lack of improvement in motor abilities in children with hearing loss following intervention was reported. Data presented here demonstrate a trend of improved motor development for children participating in exercise intervention, and a continued decline for those in the placebo group. These results indicate that the progressive nature of the developmental delay was reversed following exercise intervention. Divergent results reported here may be explained, at least in part, by the lack of comprehensive testing of vestibular function and postural control in the previous reports [13,14], thus limiting the intervention to practice of balance. In addition, the nature of the hearing loss was not reported, and the children in these studies [13,14] were beyond the critical period of balance development. It is possible that age at the time of intervention affected results. Furthermore, the sensory organization deficit identified in children with SNHI and concurrent vestibular deficit, as well as evidence of the relationship between the motor and vestibular deficits suggest that intervention should focus on improving visual and somatosensory effectiveness, as was done here. Our intervention focused on encouraging substitution and the development of somatosensory and vision abilities. The successful improvement of sensory effectiveness ratios would support this idea.

The identification of deficient visual and somatosensory effectiveness in postural control pre-intervention supports previous reports of multi-modal sensory interdependence [26]. Although the children failed somatosensory and vision effectiveness ratios, clinical screening of these modalities indicated no impairment. It may be postulated that loss of vestibular function impairs the development of functional effectiveness of sensory modalities in behaviors in which the modalities typically interact (i.e. postural control). Results presented here suggest that intervention to improve these functions was effective. As predicted by power analysis, improvement in the exercise group was not significant. However, when all subjects had participated in exercise intervention and the data merged, the functional effectiveness of somatosensation and vision in postural control significantly improved to within the normative range. This improvement in sensory functional effectiveness may have contributed to the improvement in motor development. Interestingly, gains made by the placebo group after exercise intervention were significant, despite the groups being similar in age, VOR function, group size, and initial scores. It is possible that otolith function was not similar in the two groups. However, this type of testing was beyond the scope of this study.

7. Conclusion

The results presented indicate that exercise intervention focused on substitution strategies may halt the progression of motor development delay and enhance postural control abilities of children with SNHI and vestibular impairment. Furthermore, these results suggest that testing of vestibular, motor, and postural control function, as well as intervention for deficiencies identified, is warranted in pre-school aged children with SNHI. Longitudinal studies with larger numbers of children over longer intervals of intervention are warranted to fully examine the optimal age for the provision of intervention and to determine if gains achieved persist. Testing of otolith as well as canal vestibular function may provide insight regarding the mechanisms of improvement.

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