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What is This?
A preliminary randomized controlled study on the effectiveness of vestibular-specific neuromuscular training in children with hearing impairment

Venkadesan Rajendran¹, Finita Glory Roy¹ and Deepa Jeevanantham²

Abstract

Objective: To determine the effectiveness of vestibular-specific neuromuscular training on motor skills, balance and health-related quality of life in children with hearing impairment.

Design: Controlled, randomized, preliminary study.

Setting: Rehabilitation school for children with hearing impairment.

Subjects and intervention: Twenty-three children with mean age of 7.5–8.1 years with hearing impairment were randomized to either the intervention or the control group. Children in the experimental group (n = 11) participated in vestibular-specific neuromuscular training for six weeks and the children in the control group continued their regular activities followed at school.

Outcome measures: Measurement of motor skills (Test of Gross Motor Development-2), postural control (Pediatric Reach Test, One Leg Standing Balance Test and postural sway meter) and health-related quality of life (PedsQL Generic Core Scale).

Results: Following intervention, the scores of motor skills (Test of Gross Motor Development \( P = 0.02 \); throw for distance \( P = 0.042 \); kick for distance \( P = 0.08 \); jump for distance \( P = 0.001 \); 15-yard dash \( P = 0.001 \)), postural control measures (Pediatric Reach Test \( P = 0.001 \); One Leg Standing Test \( P = 0.03 \); and anteroposterior sway (eyes open \( P = 0.007 \), eyes closed \( P = 0.03 \)); mediolateral sway (eyes open \( P = 0.014 \), eyes closed \( P = 0.017 \)) and health-related quality of life (\( P = 0.01 \)) improved significantly in the experimental group and not in the control group.

Conclusion: The findings of the study suggest that vestibular-specific neuromuscular training programme may improve the motor skills, balance and health-related quality of life in children with hearing impairment.

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Introduction
Childhood hearing impairment is a significant public health problem, which is associated with long-term academic and communicative difficulties. Besides this communication deficit, which is a major impediment, hearing impairment is also associated with other physical deficits such as vestibular-related impairments. The results of recent investigations have revealed that children with hearing loss may also present with balance and/or motor deficits. Moreover, it is postulated that these deficits are related to damage to the vestibular system. Childhood deafness often causes psycho-intellectual and social developmental disorders in children because they have difficulty interacting with their surroundings. Furthermore, the literature reveals that hearing-impaired children, both with and without motor impairment, have a diminished health-related quality of life. A recent systematic review has also shown that children with hearing impairment have associated vestibular-related impairments and diminished health-related quality of life.

Successful management of vestibular-related deficits in hearing-impaired children is a major challenge in clinical practice, as postural control and motor assessments are not routine procedures in hearing-impaired children. These tests are performed only when the child presents with an obvious deficit.

The typical treatment provided to hearing-impaired children is cochlear implantation. Evidence shows that deaf children with cochlear implantation did not perform better on balance and motor skills than deaf children without cochlear implantation. Suarez et al. reported that hearing habilitation with a unilateral cochlear implant has no effect on the observed sensory organization strategy. Sharon et al. found that a significant proportion of children with profound sensorineural hearing loss requiring cochlear implantation demonstrate abnormalities in static and dynamic balance. Most children with vestibular deficits develop walking ability, hence their problems are not noted. However, these children avoid outdoor games.

Interventional programmes that address motor deficits in children with hearing impairments have been discussed in the literature for many years, but no research has been done to explore their effects on health-related quality of life in children with hearing impairment.

Research evidence reveals that neuromuscular training improves balance in populations with other conditions. Incorporation of visual and vestibular sensory-specific neuromuscular training has been suggested in other areas of interest. Integrative neuromuscular training incorporates a variety of fundamental movements and exercises targeted to motor control deficits which may improve movement biomechanics and promote positive health outcomes. Such training has been recommended for children aged 6 years and older. However, the effect of vestibular-specific neuromuscular training has not been addressed in hearing-impaired children. The main aim of the present study was to evaluate the effectiveness of vestibular-specific neuromuscular training on motor skills, balance and health-related quality of life in children with hearing impairment.

Method
The study was a two-arm, six-week, randomized controlled trial. Baseline measurement was taken for all the participants after receiving a duly signed informed consent from all the participating children and their parents after explaining them clearly and completely about the nature of the study. Following baseline assessment, the participants were randomly assigned to experimental group or the control group using a computer-generated table of random numbers in presealed envelopes. The study was approved by the institutional ethical committee.

Keywords
Children, deafness, vestibular rehabilitation

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Children (n = 26) with a medical diagnosis of profound hearing impairment were recruited from a single deaf school. Inclusion criteria: children aged between 6 and 11 years with profound hearing impairment (a hearing level of >90 dB) with or without cochlear implantation, ability to understand simple instructions, ability to stand and walk independently. Exclusion criteria were: associated cognitive, physical and visual impairments, neurological, orthopaedic and cardiovascular condition. Twenty-one children met the criteria.

The vestibular-specific neuromuscular training programme was developed and administered in one-to-one sessions by an experienced physiotherapist for six weeks. The training programme was based on the existing literatures to enhance motor skills and balance.6,18–22 The feasibility of the programme was tested on two deaf children prior to the intervention period. Intervention consisted of 45-minute sessions, three times per week. Treatment sessions included activities in three categories which would enable substitution and improve movement skills18,20,23: eye–hand coordination exercises; balance retraining exercises; fundamental motor skill exercises (see appendix online). Predetermination of activities for each session was done, to assure equivalent time allotment for each category.

Instructional procedures were based on demonstration and a total communication (TC) approach. Each exercise was demonstrated before its execution to familiarize the subject with it. The instructions were repeated until the subject knew exactly what was expected from him or her. The subjects received positive reinforcement during the entire vestibular-specific neuromuscular training programme to ensure that they put in their maximum effort during each training session. The control group received no special intervention, but continued doing the activities that were being followed in the school, including classroom study and play activities.

Postural control was measured using the Pediatric Reach Test, a postural sway meter, and One Leg Standing Test. The Pediatric Reach Test measures the limits of stability on both forward and lateral directions.24 The intra-rater reliability of the Pediatric Reach Test was tested in hearing-impaired children in a standing position prior to collecting baseline data.25 The procedure was explained and demonstrated to the children. The children were asked to reach as far forward (forward reach) and to the side (lateral reach) as possible without moving their feet. Three trials were performed and the average was used for the data analysis. The children were allowed a minimum rest period of one minute between the trials. The intra-rater reliability of the Pediatric Reach Test – forward reach was ICC (intraclass correlation coefficient) 0.98, and Pediatric Reach Test – lateral reach ICC 0.96.25

The One Leg Standing Test measures the postural steadiness in a static position. It is widely used in clinical setting. This test has been used in deaf children.11 The standardized protocol of the One Leg Standing Test was used to quantify the duration. The children were instructed to stand on one leg as long as possible with a maximum of 20 seconds each trial. The procedure was explained and demonstrated, and children were also allowed to practise once with eyes open on each leg for 10 seconds. Three trials were performed with eyes open and eyes closed and the scores were summed. Good inter-rater reliability (r = 0.87–0.99) has been reported in the One Leg Standing Test with eyes open and closed.26

Postural sway during bipedal stance was measured using a sway meter, a valid and reliable tool that measures displacements of the body at waist level.27 Testing was performed under two conditions: foam eyes open, foam eyes closed. Medium-density foam surface (15 cm thick) was used, to reduce proprioceptive input from the lower limbs, requiring participants to rely on visual and vestibular input to maintain a steady stance. The children were instructed to stand with bare feet on the foam surface as still as possible for a period of 30 seconds. The anteroposterior (AP) and mediolateral (ML) sway were recorded from the outer border of sway path in the anteroposterior and lateral direction by tracing of the pen on the graph paper.

Qualitative aspects of motor skills were assessed by using Test of Gross Motor Development-2 (TGMD-2). The scale includes two skills: locomotion and object control skills.
The scoring was done according to the protocol described by Ulrich.\textsuperscript{28} TGMD-2 is a valid and reliable tool,\textsuperscript{28} and has been used to measure motor skills performance in hearing-impaired children.\textsuperscript{5} Quantitative aspects of the motor skills were assessed by measuring three trials of throw for distance, kick for distance, and jump for distance, and two trials of the 15-yard dash concurrently with administration of the TGMD-2 test items for the throw, kick, jump and run.\textsuperscript{5}

Health-related quality of life was assessed using the PedsQL 4.0 questionnaire. PedsQL 4.0 is a 23-item health-related quality of life inventory with four subdomains: (i) physical functioning (eight items), (ii) emotional functioning (five items), (iii) social functioning (five items), and (iv) school functioning (five items). It is a 5-point rating scale. All the participants were asked to answer the PedsQL 4.0 questionnaire. Depending on the reading ability of the children, the questionnaire was either read by the children themselves or was presented to them by a special educator. Scale score was not computed if more than half of items in the scale were missing.\textsuperscript{29} The PedsQL 4.0 has been used in hearing-impaired children.\textsuperscript{12} A generic health-related quality of life instrument such as PedsQL 4.0 enables us to rate the health-related quality of life of an individual and compare it across illnesses.\textsuperscript{29} The participants responded to the PedsQL 4.0 questionnaire anonymously, recording their individual ID number.

These instruments are frequently used in clinical settings and are cost effective.\textsuperscript{30} At the beginning and end of each session the investigator and special educator asked the participants if they had experienced any injuries or other problems, and the information was recorded in the participants’ exercise logbooks.

The results were analysed using SPSS software version 16. Mann–Whitney \textit{U}-test was used to analyse between-group variables. Non-parametric tests were used since the sample size was small, and the data was skewed. The level of significance was set at $P < 0.05$.

**Results**

Of the 26 children screened, 21 met the inclusion criteria and were involved in the study. The baseline characteristics of the children are listed in Table 1. All the children were from lower middle socioeconomic status. Eleven children were randomly allocated to the experimental group and ten were in the control group. Figure 1 demonstrates the progress through the trial. All the children in the experimental group completed the exercise protocol successfully.

Tables 2 and 3 demonstrate the values of the postural control, and motor skills in the experimental and control groups at baseline and following the six-week exercise intervention and also change in the values following the intervention. Analysis between the groups revealed that following intervention, the experimental and the control groups were statistically different ($P < 0.05$) in terms of postural control and motor skills.

Similarly, for the scores of PedsQL, the total scores of the baseline health-related quality of life increased from 45.41 (32.29–66.6) to 63.09 (43.31–77.2) in the experimental group as documented in Table 4. Analysis of PedsQL scores following intervention showed that there was a statistically significant difference in the total health-related quality of life scores between the two groups.

**Table 1.** Baseline characteristics

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Control group ($n = 10$)</th>
<th>Experimental group ($n = 11$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male: 6; Female: 4</td>
<td>Male: 8; Female: 3</td>
</tr>
<tr>
<td>Age (years)\textsuperscript{a}</td>
<td>8.1 (6–11)</td>
<td>7.5 (6–11)</td>
</tr>
<tr>
<td>Weight (kg)\textsuperscript{b}</td>
<td>25.6 (18–32)</td>
<td>24.5 (17.5–33)</td>
</tr>
<tr>
<td>Height (cm)\textsuperscript{b}</td>
<td>115.3 (106–122)</td>
<td>113.2 (104–124)</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Mean (range).
Discussion
The purpose of this study was to examine the effectiveness of the vestibular-specific neuromuscular training in postural control, motor skills and health-related quality of life in hearing-impaired children. The main finding of this study is that following six weeks of a vestibular-specific neuromuscular training programme, the children with hearing impairment improved in postural control, motor skills performance and health-related quality of life. This
improvement indicates that a six-week protocol of exercise training programme can bring about a statistically significant difference.

Improvements in postural control and motor skill performance parameters in the experimental group may be attributed to the visual and vestibular-specific exercise programme that enhances neuromuscular control and substitution. The results of our study are in accordance with the previous reports, in which exercise intervention improved sensory organization for postural control and halted progressive motor delay. However, our results are contrary to a study by Effgen. Contrasting results with the Effgen study may be due to incorporation of the traditional exercise programme used to facilitate static balance ability. In addition, the exercise programme was provided only for 10 days. It is possible that the nature of the exercise programme, intensity, frequency and duration affected results. Moreover, it has been postulated that intervention should focus on improving substitution as was done here and in the study by Rine et al. Our intervention focused on enhancing substitution by development of visual and somatosensory abilities, and incorporation of fundamental motor skills which facilitates neuromuscular control.

According to the authors’ knowledge, this is the first study that has explored the effectiveness of an intervention programme on health-related quality of life in hearing-impaired children. The findings of this study demonstrate that an exercise intervention programme can effectively improve the health-related quality of life of children with hearing impairment. The comparison between the experimental and control groups suggests that this improvement in the health-related quality of life may be attributed to the exercise intervention.

The physical scores of health-related quality of life in the experimental group showed significant improvement compared to the control group. The improvement may be attributed to the intervention programme, which focused on encouraging the motor and balance activities which would have improved the physical scores of health-related quality of life.

<table>
<thead>
<tr>
<th>Scales</th>
<th>Test</th>
<th>Experimental group</th>
<th>Control group</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Median (range)</td>
<td>Change (range)</td>
<td>Median (range)</td>
</tr>
<tr>
<td>PRT, Forward reach (cm)</td>
<td>Pre</td>
<td>13.5 (10.9–19.0)</td>
<td>5.99 (4.4–6.8)</td>
<td>15.5 (13.0–20.0)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>20.1 (17.2–20.1)</td>
<td>15.6 (13.6–20.4)</td>
<td>13.0 (12.0–16.0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>75.4 (65.1–92.1)</td>
<td>9.2 (6.0–13.6)</td>
<td>76.8 (68.1–92.1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>87.1 (75.2–98.2)</td>
<td>20.1 (17.2–20.1)</td>
<td>78.0 (70.2–93.1)</td>
</tr>
<tr>
<td>OLS-EO (seconds)</td>
<td>Pre</td>
<td>20.8 (9.2–38.4)</td>
<td>5.0 (2.8–7.0)</td>
<td>20.0 (10.1–39.1)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>24.1 (15.4–44.5)</td>
<td>20.3 (11.5–40.1)</td>
<td>95.9 (81.6–131.2)</td>
</tr>
<tr>
<td>OLS-EC (seconds)</td>
<td>Pre</td>
<td>91.3 (80.6–130.5)</td>
<td>14.3 (10.2–18.2)</td>
<td>96.2 (84.9–132.1)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>107.0 (92.9–142.6)</td>
<td>13.0 (12.0–16.0)</td>
<td>103.0 (91.2–145.6)</td>
</tr>
<tr>
<td>AP sway–EO (mm)</td>
<td>Pre</td>
<td>40 (23–53)</td>
<td>−7.18 (−12 to −1)</td>
<td>43.5 (24–53)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>31 (20–44)</td>
<td>43.5 (23–55)</td>
<td>52 (38–72)</td>
</tr>
<tr>
<td>AP sway–EC (mm)</td>
<td>Pre</td>
<td>50 (36–70)</td>
<td>−8.09 (−12 to −3)</td>
<td>54.5 (36–70)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>41 (30–60)</td>
<td>54.5 (36–70)</td>
<td>71.0 (45–82)</td>
</tr>
<tr>
<td>ML sway–EO (mm)</td>
<td>Pre</td>
<td>70 (40–80)</td>
<td>−11.09 (−16 to −5)</td>
<td>70 (45–85)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>54 (35–70)</td>
<td>70 (45–85)</td>
<td>101.5 (62–128)</td>
</tr>
<tr>
<td>ML sway–EC (mm)</td>
<td>Pre</td>
<td>98 (60–125)</td>
<td>−14.6 (55–98)</td>
<td>102 (65–134)</td>
</tr>
</tbody>
</table>

PRT, Pediatric Reach Test; OLS, One Leg Standing Test; EO, eyes open; EC, eyes closed; AP, anteroposterior; ML, mediolateral.
In the present study, the experimental group showed significant improvement in the psychosocial scores of health-related quality of life following the exercise intervention. Fox studied the influence of physical activity on mental well-being through a narrative review and summary. He stated that regular, moderate exercise should be considered as a viable means of treating depression and anxiety, and that it is effective in improving mental well-being. The literature shows that moderate intensity exercise has a positive effect on mood. Lawlor and Hopker aimed to determine the effectiveness of exercise intervention in the management of depression by a systematic review and meta-regression. Their results showed that people who exercise are ‘1.1 standard deviations less depressed than non-exercisers’. Tomporowski et al. examined the effects of exercise on children’s intelligence, cognition and academic achievement through review. They stated that exercise may be a simple and important method of enhancing mental functioning central to cognitive development. Evidence suggests that exercise can improve the social well-being and

### Table 3. Pre–post values and change in the motor skills in the experimental and control groups

<table>
<thead>
<tr>
<th>Scales</th>
<th>Test</th>
<th>Experimental group</th>
<th>Control group</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Median (range)</td>
<td>Change (range)</td>
<td>Median (range)</td>
</tr>
<tr>
<td>TGMD- Object control subtest</td>
<td>Pre</td>
<td>37 (26–39)</td>
<td>4.4 (3–8)</td>
<td>35 (27–40)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>40 (31–42)</td>
<td></td>
<td>34 (26–42)</td>
</tr>
<tr>
<td>TGMD- Locomotion subtest</td>
<td>Pre</td>
<td>38 (27–41)</td>
<td>3 (1–5)</td>
<td>37 (28–41)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>41 (32–42)</td>
<td></td>
<td>37.5 (27–41)</td>
</tr>
<tr>
<td>TGMD-Total score</td>
<td>Pre</td>
<td>75 (53–79)</td>
<td>7.4 (5–10)</td>
<td>72 (55–81)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>81 (63–84)</td>
<td></td>
<td>73 (54–82)</td>
</tr>
<tr>
<td>Throw for distance (ft)</td>
<td>Pre</td>
<td>35.1 (22.1–42.1)</td>
<td>4.8 (2.2–8.5)</td>
<td>38.1 (22.1–43.1)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>43.2 (28.7–47.9)</td>
<td></td>
<td>37.4 (22.8–42.5)</td>
</tr>
<tr>
<td>Kick for distance (ft)</td>
<td>Pre</td>
<td>26.1 (12.1–33.2)</td>
<td>7.1 (6.0–8.07)</td>
<td>28.2 (16.4–38.4)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>34.2 (19.4–39.2)</td>
<td></td>
<td>28.5 (15.9–37.2)</td>
</tr>
<tr>
<td>Jump for distance (m)</td>
<td>Pre</td>
<td>0.9 (0.8–1.3)</td>
<td>0.39 (0.1–0.5)</td>
<td>1.1 (0.89–1.5)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>1.4 (1.3–1.5)</td>
<td></td>
<td>1.0 (0.8–1.4)</td>
</tr>
<tr>
<td>15-yard dash (seconds)</td>
<td>Pre</td>
<td>3.3 (1.5–4.1)</td>
<td>−0.9 (−1.5 to −0.3)</td>
<td>3.5 (1.0–4.2)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>2.5 (1.2–2.7)</td>
<td></td>
<td>3.1 (1.0–5.3)</td>
</tr>
</tbody>
</table>

**TGMD, Test of Gross Motor Development.**

### Table 4. Pre–post values and change in the health-related quality of life in the experimental and control groups

<table>
<thead>
<tr>
<th>Scales</th>
<th>Test</th>
<th>Experimental group</th>
<th>Control group</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Median (range)</td>
<td>Change (range)</td>
<td>Median (range)</td>
</tr>
<tr>
<td>Physical health</td>
<td>Pre</td>
<td>50.0 (31.2–59.3)</td>
<td>15.9 (6.2–23.5)</td>
<td>50.0 (31.2–75.0)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>62.5 (43.3–69.5)</td>
<td></td>
<td>50.0 (31.2–75.0)</td>
</tr>
<tr>
<td>Psychosocial health</td>
<td>Pre</td>
<td>50.1 (23.3–83.3)</td>
<td>12.28 (1.6–17.8)</td>
<td>53.3 (31.6–68.3)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>64.1 (40.0–85.0)</td>
<td></td>
<td>55.3 (33.3–68.3)</td>
</tr>
<tr>
<td>Total scores</td>
<td>Pre</td>
<td>45.4 (32.2–66.6)</td>
<td>14.1 (8.6–22.3)</td>
<td>45.4 (32.2–66.6)</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>63.0 (43.31–77.2)</td>
<td></td>
<td>57.0 (43.3–7.2)</td>
</tr>
</tbody>
</table>
functional ability to work. It may also increase feelings of happiness and life satisfaction, social affiliation and significance in relation to self-esteem.\(^{35}\) The social interaction provided during the exercise programme may have contributed to the improvement in psychosocial aspect of health-related quality of life in the experimental group.

Compliance to the intervention was excellent with no drop-outs. Hence, we can safely say that the visual and vestibular-specific exercise training implemented in this study was feasible for children with hearing impairment.

The present study has some limitations. Blinding was not done as the assessor knew which group the child was in. The children in the control group did not receive any intervention; hence, no attention was given to them. The sample size was small and the follow-up effect of vestibular-specific neuromuscular training programme was not seen. Moreover, as this was a single-centre study, only children from one school were recruited, which together with the limited sample size means that the results may not be representative of a wider population. Therefore, studies with larger sample size and follow-up are warranted to confirm the benefits of the vestibular-specific neuromuscular training programme.

In conclusion, the results of the present study indicate that a vestibular-specific neuromuscular training programme focused on substitution and neuromuscular coordination may improve postural control and motor skills, which would enhance the health-related quality of life in hearing-impaired children.

### Clinical messages
- Postural control, motor skills and health-related quality of life improves in children with hearing impairment following a six-week vestibular-specific neuromuscular training programme.
- Such intervention programmes are feasible.

### Acknowledgements
We would like to thank the children who participated in the study. Our special thanks to Dr Doreen Bartlett and her team for granting permission to use Pediatric Reach Test. Also, to the Mapi Trust, France and Dr James Varni research group, USA who provided the PedsQL 4.0 questionnaires free of charge.

### Conflict of interest
None.

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